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AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES

A report of work done by scientists of 4 campuses of the University of California (Davis, Berkeley, Santa Barbara and Riverside) under NASA Grant NGL 05-003-404

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PROCEDURAL MANUAL FOR DEVELOPING A GEOBASE INFORMATION SYSTEM

(An Outgrowth of Remote Sensing-Related Water Demand Studies in Central California)

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PROCEDURAL MANUAL FOR DEVELOPING A GEOBASE INFORMATION SYSTEM

INTRODUCTION

During the past several years personnel of the Geography Remote Sensing Unit (GRSU) on the Santa Barbara Campus of the University of California have concentrated their work under this NASA grant on the performance of remote sensing-related water demand studies in the predominantly agricultural lands of Central California. In the course of this work it has become increasingly apparent that greatly improved efficiency could result if a geobase information system could be developed that would permit remotely sensed data to be used in conjunction with conventional resource inventory data in inventorying an area's "total resource complex." This chapter addresses the procedures, alternatives, considerations and examples in the development of a geobase information system for resource managers. In addition, a case study of the on-going development of a geobase information system incorporating remotely sensed data is presented in Chapter 1. That study serves to summarize some of the primary considerations in the development of a county-level information system.

It is to be emphasized that this Procedural Manual is complementary to, rather than duplicative of, the one currently being developed by personnel of the Remote Sensing Research Program on the Berkeley Campus. It is true that the manual being developed by that group also seeks to provide a step-wise procedure for using remote sensing-derived information in the inventory of an area's "total resource complex." However, the area being dealt with by that group is an almost entirely wildland area in California's Sierra Nevada Mountains where timber and forage production are primary resource management objectives. Furthermore, the ancillary data pertaining to that area's natural resources is likely to be of a significantly different nature than the ancillary data pertaining to California's Ventura County--the coastal area in which efforts of our GRSU are concentrated.

The need for improvement in resource information handling is increasing as the information requirements of resource management agencies at the international, national, state, regional and local levels continue to expand. To effectively inventory the resource complex, resource managers are faced with the need to store, update and access environmental data in an accurate and efficient manner.

It is emphasized that satisfying the resource managers data needs must be given highest priority, both in the development of data categories and in the formulation of techniques for data interrogation and analysis. The operational downfall of many geographic information systems in the past has been the result of a failure to meet the needs of the intended user. All too often packaged systems have been purchased and implemented, with little consideration of what the user agency requires. Ideally an information system should be custom designed to meet user requirements.

Phase I ADDRESSING USER NEEDS

A critical phase in the development of a geobase information system is to determine the information necessary for the day to day decisions which affect resources. This can be accomplished through a survey of the potential users of a geobase information system. The objectives of such a survey would be to:

1) determine existing agency (or departmental) methods, capabilities and tasks - this includes the roles of the tasks in decision making, frequency of the tasks, and priorities of the tasks, and
2) determine the data used in performing specific tasks, their characteristics, how they were processed, and from what sources they were obtained.

Care should be taken to insure that data expressed as needed is done so according to current agency practices. It should not be an agency "wish list" and should include data items actually used or required to meet current responsibilities, whether actually used or not.

The users surveyed should be representative of a larger, potential community of users of geobase information systems and should include key agencies (or departments) whose expected major use of an operational system would strongly influence system design. The survey team should work closely with users who are representatives of key agencies, for example, those responsible for the management and development of renewable and nonrenewable resources, for transportation planning and development, for regional planning, and for environmental protection.

Survey Strategy

The survey should consist of an initial interview and a follow-up visit designed to acquaint agency personnel with the objectives of the user need survey and to familiarize the interviewers with the agency and its activities. The interviewers should employ a series of general questions designed to obtain systematic and quantifiable responses and to facilitate systematic documentation of results. These questions should be related to current resource management and planning decision making functions of the agency and the legal authority and requirements for these functions. The activities of these agencies should be organized into categories of task and sub-task wherever possible in order to determine the data categories pertinent to each task or sub-task.

An underlying purpose of the initial interview should be to elicit unbiased responses regarding the perspective of the agency's personnel on the characteristics and capabilities of remote sensing-based products in order to acquire an initial estimate of training and/or education needs of the staff and supervisors. Upon completion of the initial round of interviews, the appropriate seminars, discussions, and workshops should be initiated to acquaint <u>key</u> personnel with the uses of LANDSAT data and other remotely sensed products. These training sessions are often available from the regional centers of the National Aeronautics and Space Administration (NASA), other federal agencies (USDI, USDA), local educational institutions, and private industry research groups.

The second-round interviews should be designed (1) to evaluate, correct, and update the survey information obtained from round one, and (2) to prioritize the agency's management functions, tasks, and the associated data categories.

Determining Priority Data

As stated previously, the activities of the agency should be organized into categories of task and sub-task wherever possible in order to determine the data categories pertinent to each. For each management function, particular discipline-oriented analytical tasks should be identified as to their priority, frequency of occurrence, the initiating agency, the reason for initiating, and the agency that performs it. Once these tasks have been identified and prioritized then the specific information elements needed to perform each task should also be identified. Details of interest regarding these information elememts include;

- data categories (e.g. soil, vegetation, topography, land use, etc.)
- data formats (e.g., maps, photographs, tabular, digital file structures, etc.)
- data sources (e.g., NASA, USFS, SRS, in-house, contract, etc.)
- processing methods (e.g., what was done with the "raw" data)
- accuracy requirements (e.g., classification accuracy and spatial location)
- resolution requirements (e.g., scale, mapping minimum, etc.)
- temporal constraints (e.g., acceptable delay times from request to receipt of data or the "age" of the data upon receipt)

Data categories to be included in a geobase information system should represent a variety of technical characteristics. The categories selected should have multiple uses by many agencies or else should be central to the operations of at least one agency. A shared or common date base that meets the requirements of a number of agencies can greatly reduce superfluous or duplicative data and thus greatly reduce the cost of acquiring data.

Data Sources

When considering the most appropriate source for required data, the selection should be based upon the accuracy of the data, cost, resolution, timeliness, and prioritized need. Data requirements may differ from agency to agency and department to department, which implies a variety of data sources may be necessary. The following (Eastwood, et al) is a sample or partial listing of data needs and characteristics pertinent to regional and local land use planning.

Eastwood, et al., "Program on Earth Observation Data Management System (EODMS)", Final Report, Center for Development Technology, Washington University, 1976.

Data Needs and Characteristics - Land Use Planning: Regional and Local Level

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DATA TYPE	DATA NEED	CURRENT SOURCE	FORMAT	SCALE	RESO-LU-TION	FREQUENCY OF UPDATE	TIME CONSTRAINT	COMMENTS
Agriculture	livestock prices	State	table	---	---	annual	---	listing from MO; assumed for other states
	grain prices	State	table	---	---	annual	---	
	market trends	State	table	---	---	annual	---	
	livestock receipts	State	table	---	---	annual	---	
	square feet of glass per green-house	State	table	---	---	once	---	
	degree of crop damage	State	table	---	---	annual	---	
	livestock acreage	USDA SRS	table	---	---	annual	---	
	crop acreage	USDA SRS	table	---	---	annual	---	
	crop location	USDA SRS	table	---	---	annual	---	
	crop production	USDA SRS	table	---	---	annual	---	
	total farms	Census	graph	---	---	annual	---	
Vegetation	type of vegeta-tion cover	USDA USCS	map	1:250,000	40m	5 years	---	
	type of vegeta-tion acreage	USDA USCS	table	1:250,000	---	5 years	---	
	locational pattern of vege-tation cover	USDA USCS	map	1:250,000	40m	5 years	---	
Soils	soil locational patterns	SCS	map	1:24,000	500'-1000'	once	---	
	slope	SCS	map	1:24,000	---	once	---	
	permeability	State	table	---	---	once	---	
	bearing strength	State	table	---	---	once	---	
	shearing strength	State	table	---	---	once	---	
	composition	State	table	---	---	once	---	
	soil type	SCS	table	---	---	once	---	
	soil series name or number	SCS	table	---	---	once	---	
	soil fertility	SCS	table	---	---	once	---	
	physical proper-ties	SCS	table	---	---	once	---	

Data Needs and Characteristics - Land Use Planning: Regional and Local Level (continued)

DATA TYPE	DATA NEED	CURRENT SOURCE	FORMAT	SCALE	RESOLUTION	FREQUENCY OF UPDATE	TIME CONSTRAINT	COMMENTS
Soils (Cont)	subsurface drainage	State	map	1:250,000	500' or better	once, as needed	---	
	topography	USGS	map	1:500,000	500'	once, as needed	---	10' contours
	local relief	USGS	map	1:24,000	---	once, as needed	---	
	seismic risk zone	E.S.S.A. Coast and Geodetic Survey USGS	map	1:24,000	---	once, as needed	---	
	terrain type	E.S.S.A. Coast and Geodetic Survey USGS	map	1:24,000	---	once, as needed	---	
	geochemical properties	USGS	table	---	---	once, as needed	---	
	rock type	USGS	table	---	---	once, as needed	---	
	geologic units							
	structure of unit	USGS	table	---	---	once, as needed	---	
	orientation of unit	USGS	table	---	---	once, as needed	---	
	depth to bedrock	USGS	table	---	---	once, as needed	---	
	thickness of bedrock	USGS	table	---	---	once, as needed	---	
	geomorphic feature type	USGS	table	---	---	once, as needed	---	
	geomorphic feature orientation	USGS	table	---	---	once, as needed	---	
	geologic history	USGS	table	---	---	once, as needed	---	
	tectonic data	USGS	table	---	---	once, as needed	---	
	areal extent	USGS	table	---	---	once	---	
	age	USGS	table	---	---	once	---	
	correlative units	USGS	table	---	---	once	---	
	topographic cross-section	State	diagram	---	---	once	---	
	foundation depth requirements	State	text	---	---	once	---	
	engineering geology	State	map	1:500,000	---	once	---	

Phase II DATA ACQUISITION

Data acquisition is the process by which potential information sources are obtained. It is a necessary step in the development of an information system, and an important, on-going concern of all resource managers. Of particular concern to the resource manager are:

- Where and how to obtain specific data products.
- What is the least expensive means of acquiring a specific data product.
- What are the data attributes (accuracy, resolution) of the data product to be acquired.

Most of these concerns come up in the user needs phase of information system development, and have been addressed appropriately in that section of this manual.

The task of acquiring data is essentially a manual exercise, once decisions are made concerning appropriate data sources. The data may be physically acquired in one of the three manners by:

- Obtaining existing data
- Contracting new data coverage
- Collecting data "in house"

As we will see, each of these three data acquisition modes have inherent advantages and disadvantages that must be considered prior to a choice of the optional mode.

Irrespective of which of the three modes that the data is acquired by, it is physically gathered by one of two methods, distinguished by the relative position or vantage point from which the phenomenon is recorded. These two methods are generalized as:

- Ground or field survey methods
- Remotely sensed methods

The more conventional ground or field survey methods involve on site, in the field observation and recording of data. By remote sensing, we mean the recording of data at an observation point away from the phenomena (from an air or space craft). Here data is usually recorded in the form of an image, and the image is later analyzed to extract pertinent information. Both methods have their advantages and disadvantages, with the appropriateness of the method to be used depending on the type of data that is to be collected. In general:

- Ground methods allow for greater detail in data collection
- Remote sensing methods offer the ability to simultaneously collect a greater amount of data for a larger area.

A further consideration of data acquisition is the compatibility between levels of sophistication of the information system and the potential data sources that will be input. This compatibility or appropriateness is related to the data structure format (e.g. map overlay, grid overlay, digital). It is obvious that the acquisition of digital data on magnetic tape would be inappropriate as direct input to a less-sophisticated information system that relies on hard copy maps.

Existing Sources

Existing data sources tend to be the most cost effective, yet are such that the user has little or no control over their specifications. The idea of purchasing "existing-ready-to-use" data products is certainly appealing considering the usual time and cost savings associated with them.

Existing sources fall into the categories of:

- Mass produced data products generated by government agencies acting as central distribution houses. Examples of such agencies are the U.S. Geological Survey (USGS), U.S. Department of Agriculture USDA, and the National Aeronautics and Space Administration who produce a variety of map, tabular and photographic data products.

- Data sources produced by other institutions or agencies for their own information needs, that are available for use by the rest of the resource management community. Such data is available from agency counterparts at other levels of government, as well as universities and private industry research groups.

The usual cost effective, high quality nature of existing data sources often makes them a desirable source for satisfying general information requirements. Data products that may be produced once, reproduced for distribution and then require infrequent updating are quite cost effective. Products of this type are usually associated with fairly stable phenomena such as topography, soil type and lithology (rock type). Data for more dynamic phenomena (crop type, land use, hydrology) will require more frequent, updating making the data products more expensive and possibly unobtainable in a pre-existing form.

Remotely sensed data provide a considerable advantage in this instance for two reasons:

1) aerial photographic and image products are map-like in their information content and are readily compatible with the graphics orientation of geobase information systems (Fig. 1,2,3); and

2) the perishability of much data requires the fast, cost-effective means of updating commonly associated with remotely sensed products.

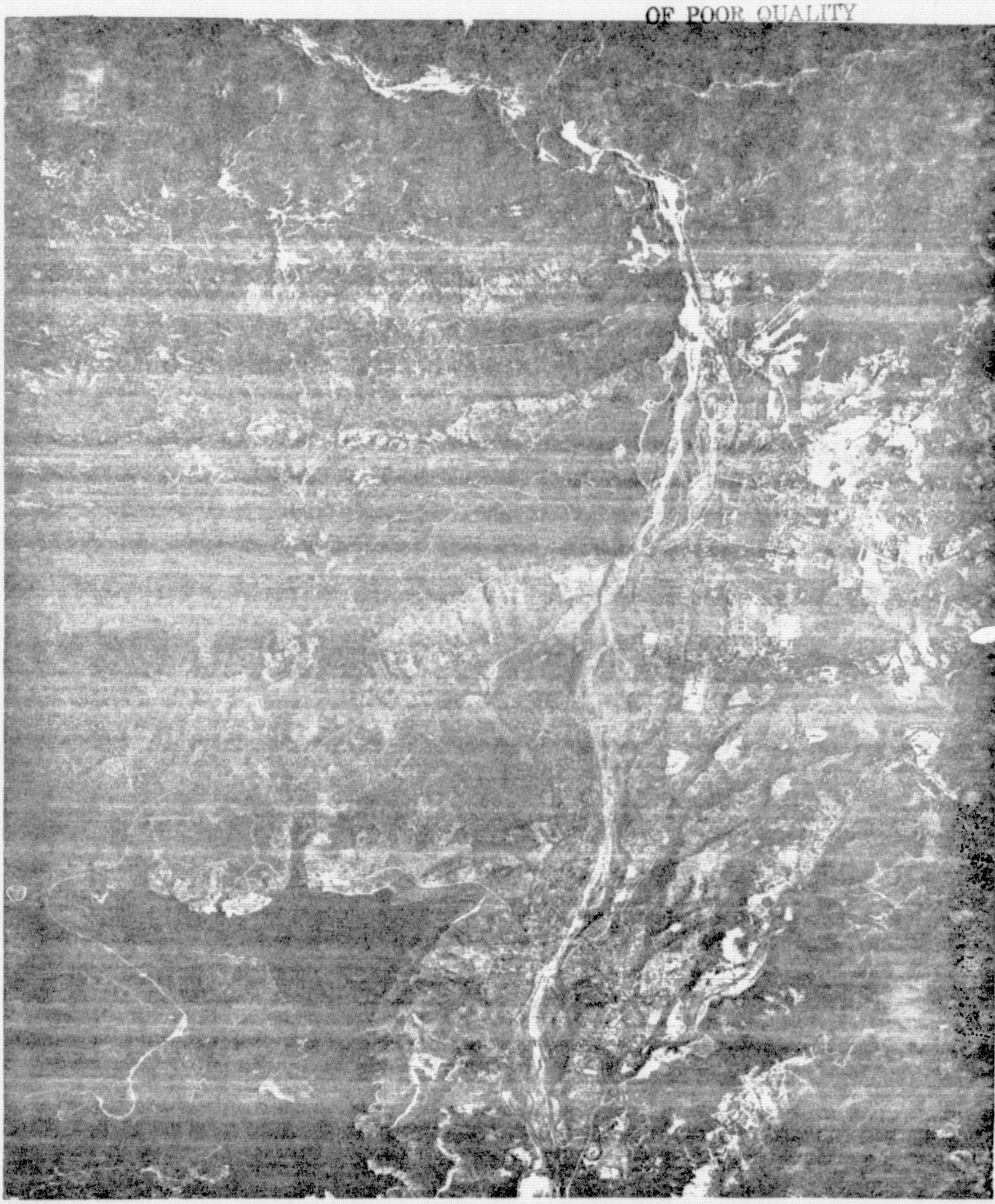

Figure 1 MATILIJA ORTHOPHOTO QUAD
U.S.G.S. 1:24,000 - scale

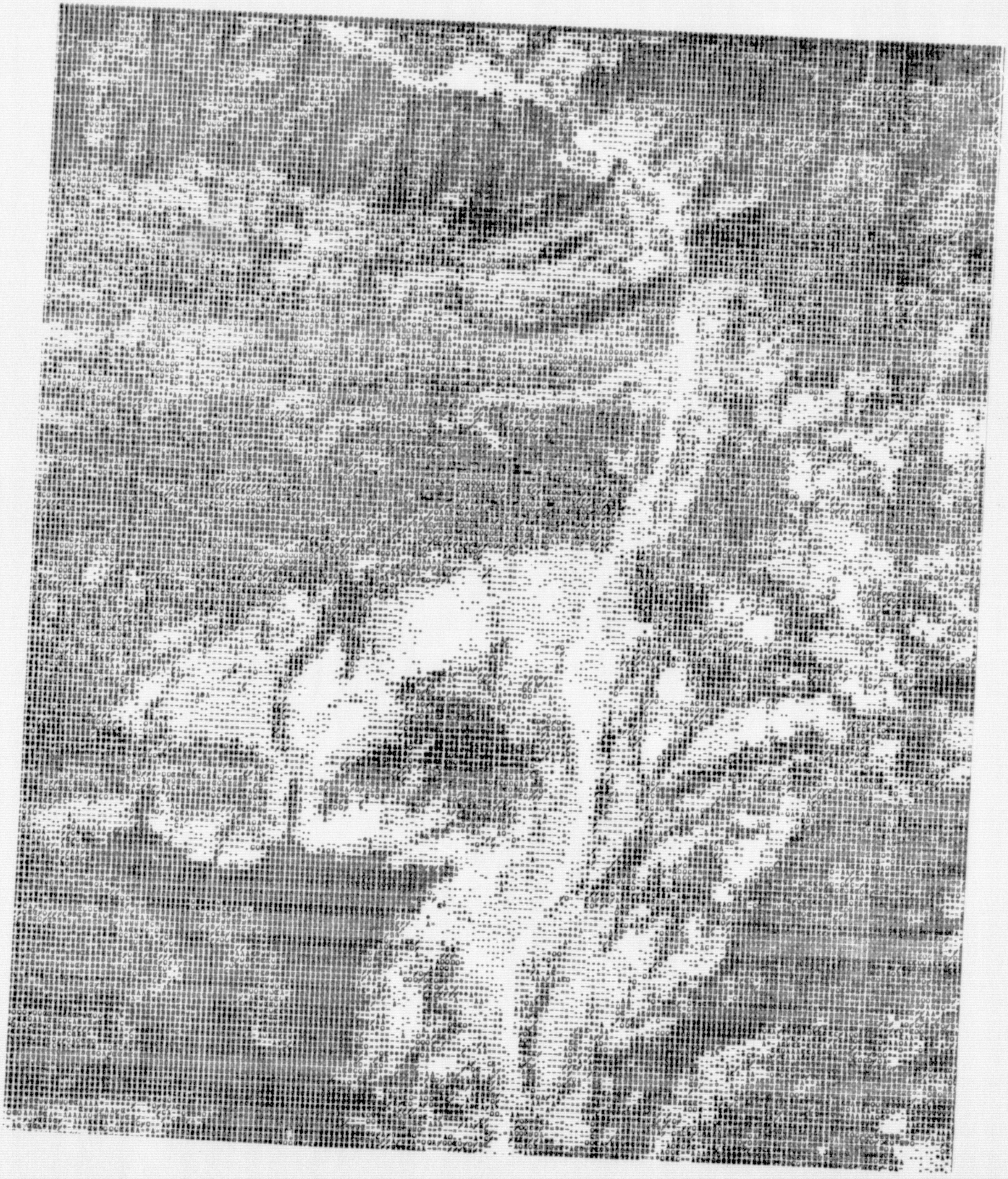

Figure 2 Line printer output of LANDSAT data which has been rectified and registered for spatial conformity with the 1:24,000 orthophoto.

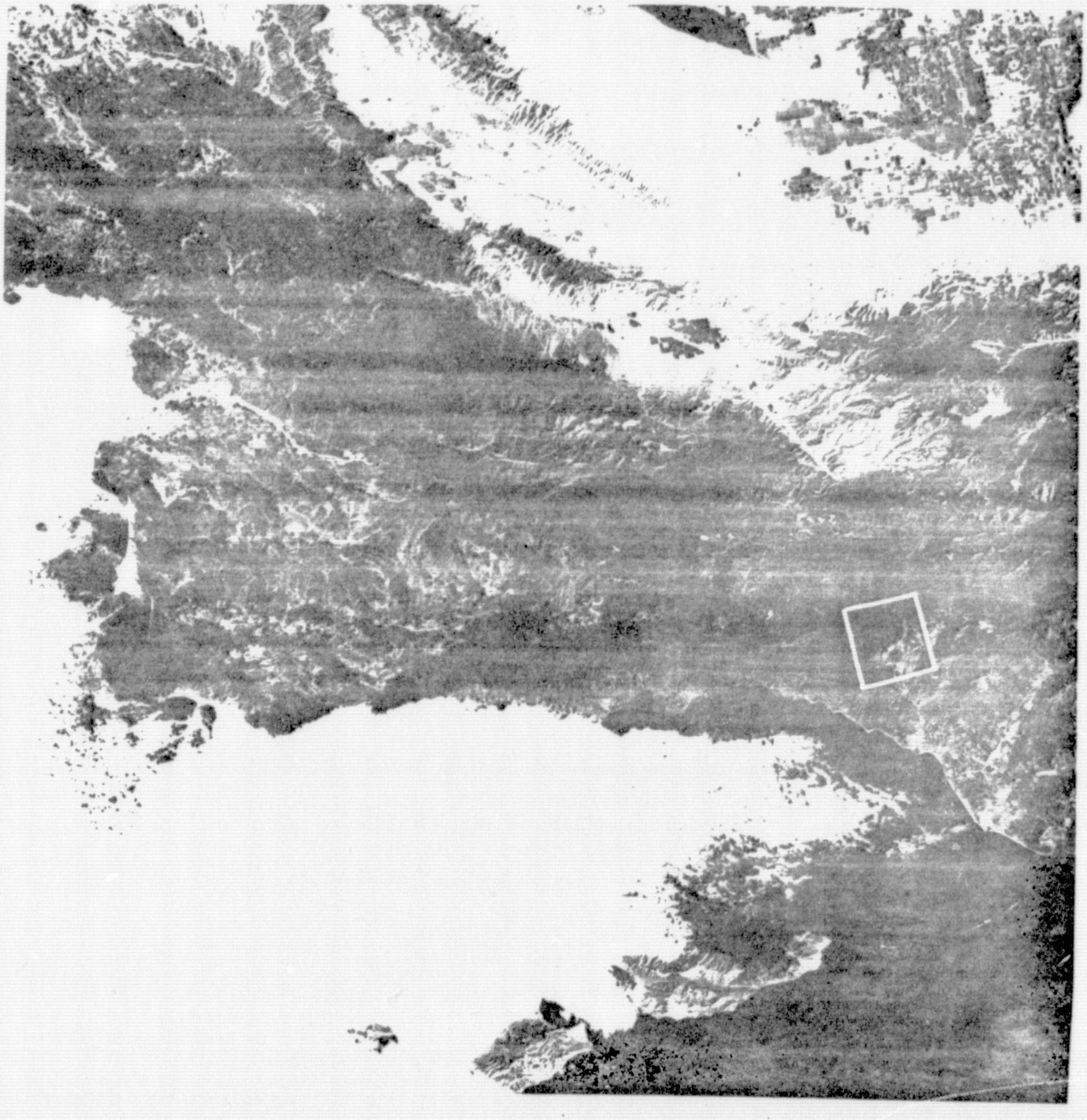

Figure 3 This LANDSAT scene consists of 1.1 acre resolution elements which are each represented by one of 128 levels of brightness. This also illustrates the areal coverage of a typical LANDSAT scene as compared to a 7½ minute quad area.

By acquiring existing data sources, one usually sacrifices control over specifications of the data attributes. This means that a resource manager may have no control over specifications such as accuracy, spatial resolution time of acquisition and extent of coverage. When an existing data source's specifications are unacceptable, it may be necessary to obtain new coverage (contracted or "in house).

Contracting New Data

To insure that exact specifications of data requirements are met, and/or to fill data voids where there are no existing sources it may be necessary to contract or make arrangements for data to be collected by an external agency. If indeed a resource manager finds that his data needs can not be met by existing sources, he has the choice of either having it collected by "in house" personnel or contracting to have it collected by some other agency or institution. Private businesses, some government agencies and many university research institutions are potential contract sources of high quality data collection and processing.

Quite often the type of data required for a particular resource management assessment is not obtainable from existing sources. When it is not physically or economically feasible for the manager and higher staff to gather the data, it must be gathered from outside sources. Data types that characteristically necessitate outside acquisition are:

- Precisely controlled, highly accurate surveyed data
- Data that requries continual acquisition and frequent updating

- Site specific data that would normally be of interest for specific agencies
- Acquisition of data that requires special equipment

Examples of data that are commonly obtained from contracted sources are

- low altitude aerial photography from private aerial survey firms
- land use/land cover maps at various scales for specific to particular environments
- land parcel surveying

Contracted data sources, may be rather expensive and are not effectively utilized by many agencies who operate under limited funding. When data acquisition is contracted through private companies associated costs may be very high especially where expensive equipment/hardware is required. There is also a constraint of understanding the legal aspects of contract obligations which often decreases the desirability of this means of acquiring data. Cost and legal constraints are an especially limiting factor for local and regional agencies who often receive limited financial support for their operations.

Collecting Data "In-house"

Many of the specific data needs of individual resource management agencies are met by involving "in-house" personnel in the collection of data. By "in-house" we are referring to staff members within the data-requiring agency itself. A good deal of the resource management data requirements are satisfied by efforts from within the agency.

If it were not for "in-house" data collections, many of the necessary management assessments would not be possible. When no sources exist for the site specific data and contracting coverage is not economically feasible, the job must be done by the interested agency itself. Quite often "in-house" personnel are more familiar with the areas for which data is collected and thus come up with a more accurate,reliable product.

As in the case for contracted coverage extensive "in-house" data acquisition may be infeasible for agencies who receive a limited amount of funding. In spite of increasing employment opportunities, having a large staff involved in data collection means that more salaries must be paid. The cost of data collection equipment must be considered as well, in determining the feasibility of "in-house" collections.

Phase III METHOD OF DATA STORAGE AND RETRIEVAL

In order to optimize the resource management process, acquired data should be stored in a systematic, organized manner. By doing so in some type of common data bank, many agency members and multiple agencies may reap the benefits of greater data handling efficiency. Efficiency is increased by knowing where to find available data and by sharing the cost of data acquisition amongst agencies. This of course assumes that various agencies share many common data needs.

A natural means of organizing, storing and retrieving data that is pertinent to resource management assessments, is through the use of geographical or locational identifiers. Geographical or locational identifiers are simply descriptors assigned to portions of data, describing the geographical location where they were acquired. By assigning the identifier or "geocoding" the data, a resource manager is able to: 1) extract information from particular geographic areas; 2) compare and/or merge different data types for the same area; and 3) supply geographic data to pertinent management models.

A geographic information system may be developed at varying levels of sophistication, depending on such things as:

- complexity and size of agencies' data requirements
- technological sophistication of agency staff and equipment
- type of decision making tasks performed by agency

Geographic information systems may range in levels of sophistication from: simply organizing and cataloguing map, other graphical, and tabular data according to geographic coordinates; to a complex computerized system with digitally stored data. All systems though, have the common characteristics of geographically organized data which may be easily extracted for input as an integrated part of the total resource management decision-making process (Fig. 4).

Whether utilizing manual or computerized storage techniques, there are a variety of data storage modes that may be used in a resource management information system. An appropriate storage mode is one that most efficiently allows for the storage and retrieval of data for specific agencies. Efficiency here is viewed as a matter of minimizing time and costs, while still inacting data requirements. Storage methods are basically differentiated by the size, shape and geometry of storage units that

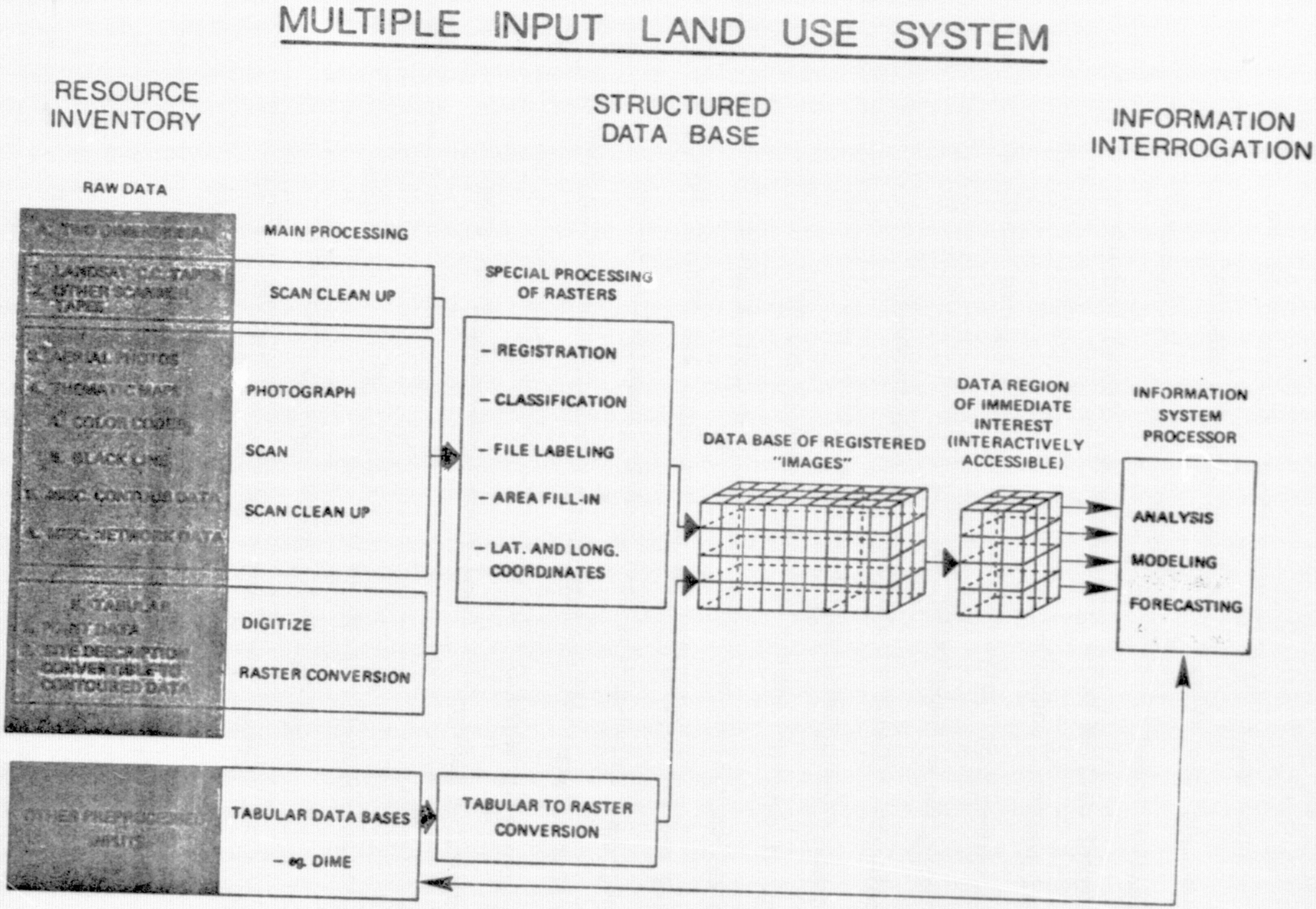

Figure 4 Geographic information systems range in levels of sophistication from organizing data according to geographic coordinates, to computerized interrogation and manipulation of digital data.

represent geographical areas on the ground. Let us take a look at some of the more common storage modes, with an understanding that the efficiency and degree of usage of each mode are constantly changing in the eyes of geographic data analysis researchers.

Catalogued Map and Tabular Data

Lowest in sophistication yet quite practical for many small resource management agencies are geographic information systems that simply consist of data products which are catalogued and stored by geographic location. Such simple systems border on being considered a data bank rather than a true information system. Even so, the fact that the data is organized and may be easily obtained by physically locating its storage place (according to its geographic location), greater efficiency in data handling may be achieved.

While attempting to inventory the entire resource complex, the resource managers may find that data sets of varying scale and format are difficult to catalogue in a single coding scheme. It may be necessary to categorically vary the method of cataloguing all map-base data of similar scale together. As long as all data for the area of coverage is organized and catalogued, increased efficiency in extracting data for resource management assessments should occur, irrespective of the geocoding scheme(s) applied. The one limiting factor here (especially for the small agencies who are most likely to utilize such a system), may be the absence of space and equipment for physically storing all data products.

Map Base Overlays

One step further in information system sophistication, yet with many added advantages is the use of one or several scales of base maps to store geographic data in an analog mode. This type of geographic information system has been most documented by Ian McHarg in his urban and environmental planning classic *Design with Nature.*

A map base overlay information system requires that all geographic data be mapped into a common base map. Considerations of common resolution requirements and total areal coverage must be considered by a particular agency prior to choosing the scale and size of the storage base map. To provide overlay capability all maps must be drawn on a stable base, transparent medium. Remotely sensed image data may be overlayed as well, but also must be of similar scale and should be geometrically rectified for accurate data reqistration. Another possibility is to map remotely sensed phenomena on a stable base medium of proper scale. If decision making processes are performed at variable levels of generalization, it may be warranted to compile data at several series of map scale.

Advantages of a base map overlay system as opposed to a simpler catalogued data system are twofold. First, it is much easier to systematically organize, store and retrieve data that is referenced to but one or a few map scales. All data-types representing the same base-map area may be organized and stored together. When it is necessary to obtain geographic data for a given area, one need only to check a small scale map of the base-map boundaries areas to see which base maps are needed to cover the area of interest.

Second and more important is the advantage of being able to overlay multiple data sets for similar areas. If the map data is drafted on a transparent medium, several data types may be compared simultaneously, adding a multi-dimensional observation capability for the resource manager.

An example of this capability is illustrated in Figure 5. Here generalized land cover and soil suitability data have been mapped on sheets of transparent, stable-base mylar. Differing categories are symbolized by varying dot or grey patterns. The data sets have been overlayed in attempts to determine areas suitable for agricultural development. Data categories have purposely been symbolized by a level of "grayness" (density of dots) that correspond to the this degree of influence on agricultural suitability. A land cover type such as grass lands will receive lighter symbols than a residential type as it is more feasible to develop the land for agriculture on a grass field than a housing tract. Similarly, soils of high fertility and shallow slope are represented by lighter shades of grey than less suitable soils of lower potential fertility. When overlayed, areas that show up the lightest should be the most suitable for agriculture. By excluding existing agricultrual lands, areas of potential agricultural development may be delineated.

Disadvantages of base-map overlay systems are related to the amount of time and man power necessary to produce map transparencies, as well as to the cumbersomeness of storing and overlaying analog data. The production of

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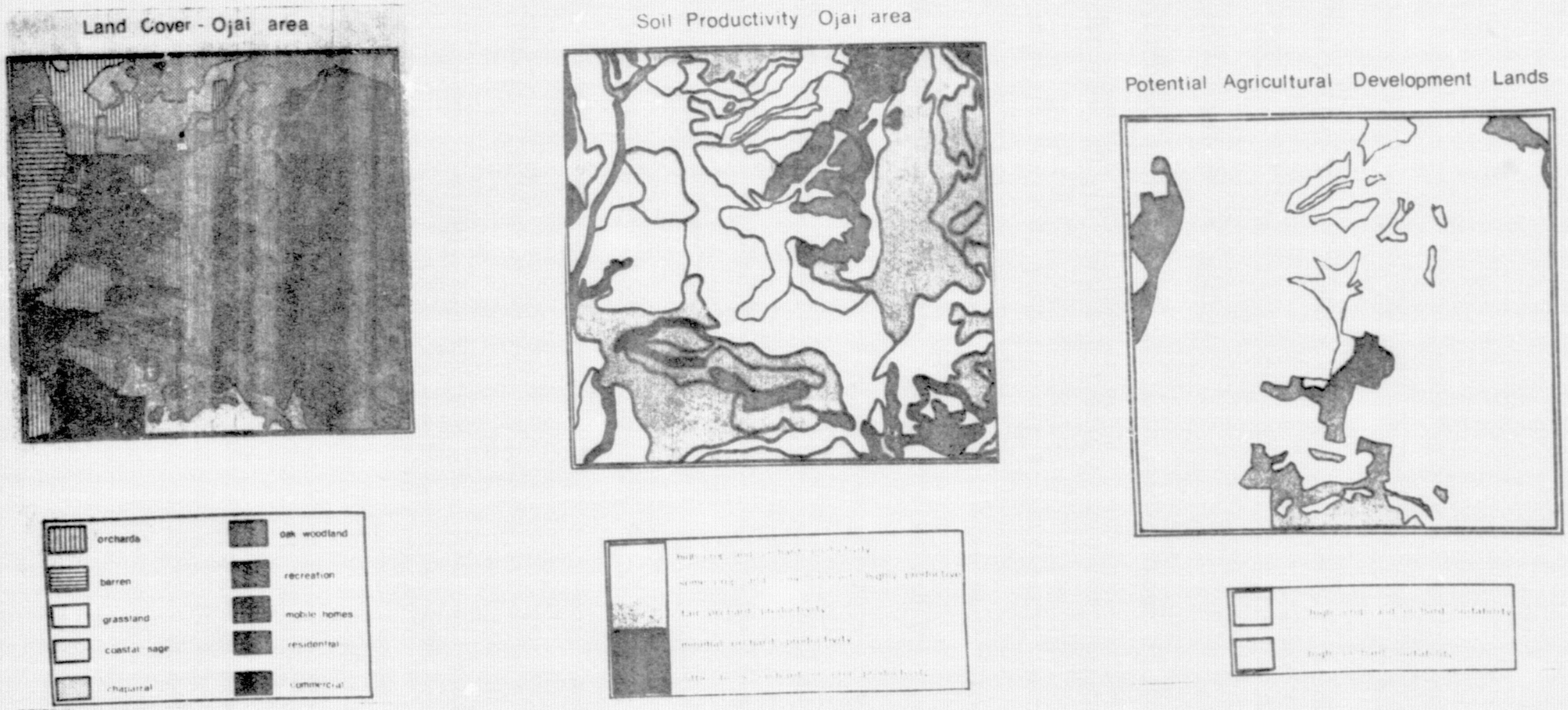

Figure 5 Data sets that are geographically registered can be "stacked" and then interpreted in a multi-dimensional mode, for example, land cover + soil productivity = potential or suitability for agricultural development.

maps may be very time consuming. If data is required for many specific data types and at varying scales, the production of transparency maps may not be feasible. The problem may be compounded when many of the data types require frequent updating.

When multiple overlays are required for a particular resource management assessment, it may be highly cumbersome or even not possible to make inferences from several overlayed maps. Here problems arise in the way that map categories are symbolized (grey tones, colors, patterns) and in how interpretable the resulting overlayed product will be. Another problem is that as the number of overlayed data sets are increased, so too are the number of potential overlay categories and polygonal fragments. These problems have influenced the development of other system types such as grid map and digital computer geobase information systems.

Computer-based Systems

Technological advances in digital computers have influenced the development of computerized geographic information systems as an attempt to increase data handling efficiency. The ability to store environmental data in a digital computer is quite appealing when one considers the obvious advantages related to the saving of storage space. Many different storage methods have been developed to further increase efficiency. Efficiencies for each of these methods are continually being examined and debated, where concerns here are related to cost, timeliness, flexibility and accuracy.

Prior to looking at the specifics of various computerized geographic information system types, let us first discuss the general characteristics of which all computerized systems share. Such a discussion may provide the resource manager some insight into an area which has been misunderstood by resource agencies and politicians, alike.

The data processing techniques concerned with the storage and retrieval of spatial data from geobase information systems are by-in-large the product of research in the field of computer cartography. Although originally oriented toward the automatic production of maps, computer cartography has more recently become engrossed in the problems involved in the efficient processing of spatial data. The efficiency and usefulness of an operational computerized geobase information system depends heavily on the capabilities of the computer cartographic techniques utilized. Although efficiency is primarily dependent upon the sophistication of computer data processing methods employed, a systems usefulness is more a function of the methods used to represent spatial data. Computer cartography's most important contributions to the improvement of geobase information systems have been the areas of data capture (digitization, raster scanning) and graphic data display (plotting, film recording, interactive graphic display).

Most spatial data is not originally found to be in computer compatible digital form and therefore must be subjected to digital conversion processing. Such a conversion requires the use of hardware equipment that interact with digital computers to derive digital data values from analog data. Manual and automatic digitizers, as well as raster scanners and interactive cathode ray terminals are all examples of digital conversion hardware that convert spatial data types such as maps and tabular indices into digital data values. By man-machine editting, fairly accurate digital portrayals of analog data may be achieved. This phase of digital data capture tends to consume a great deal of the costs and man-hours associated with operational information system. As more of the commonly used environmental data products begin to be distributed in digital form, the costliness of this phase should be significantly decreased.

The fact that the system is computerized requires that the potential user has access to a digital computer of sufficient storage core size. This combined with the complimentary need for hardware and software maintenance and programming support may temporarily limit some agencies from utilizing computer data processing techniques. Systems developed around recent advances in mini computer technology may help make computerized systems affordable to many more potential users.

In the same way that manually oriented geographic information systems vary in their degree of sophistication so to do systems that utilize computerized storage techniques. Let us briefly take a look at a few of the more common system types.

Grid based systems use an arbitrarily defined rectangular grid to store data. All data may be referenced to specific point coordinate location within the grid. The point location may be the centroid of the grid, grid intersection or similar arbitrary locations within the grid structure. Grid spacing may be fixed or variable.

Polygon or continuous line systems store spatial data in area units defined by polygons. The polygons are actually a string of line segments that connect a string of coordinate locations. Data is referenced to the entire area delimited by a particular polygon.

Image-based systems based on the image raster data type use a very fine mesh raster grid as its basic unit of data storage. Similar to a grid system, the image grid is usually a smaller fixed grid size system. Such systems depend on image raster scanning technology, where data are referenced to the small area defined by the grid.

Most geobased information in the past have used only one of the above schemes for referencing geographic data. Because digital geographic data is referenced in a variety of these storage types, most systems tend to convert the data to the base required by their system's particular data storage.

and presentation scheme. Recently, systems have been developed that store data in their original form (e.g., grid, polygon, topological structures, etc.) and thus may utilize a combination of point, polygon, and/or image raster storage-types.

Phase IV INFORMATION RETRIEVAL AND DISPLAY

Phase IV in the design of a Resource Management Geographic Information System involves an ability to access and display data that has been processed and stored within the system.

Geocoded data that is stored in a data base is of no use unless it may be accessed in some manner appropriate to a given user's need. Even simple retrieval of a single data set for a specified point, line or area may be extremely useful, if accession is quick and efficient. More sophisticated systems that interface directly with mathematical models must have the ability to interrogate multiple data sets.

Upon retrieving the required data from its system storage place, it must be displayed in a manner that lends itself to effective viewing by the resource manager. Although systems may vary greatly in the manner with which they process, store and retrieve data, final information products are generally the same from system to system. Common products such as maps, tabular listings, and graphs are produced by most types of geographic information systems. It is in these formats that resource managers are most familiar with acquiring their needed information.

Map Products

Geographic data that varies over the surface of an area can be effectively portrayed in the form of a map. By generalizing and symbolizing environmental phenomena over a two-dimensional surface both absolute and relative data characteristics are easily extractable by the resource manager. As products of a geographic information system maps may be produced in the following modes.

- Manually produced - Human cartographic drafting of geographic phenomena from field survey data, remotely sensed imagery, and overlap of map transparencies.
- Machine plotter - Machine cartographic drafting of computerized data by hardware which may utilize a variety of printing techniques, colors and formats.
- Line printer - Symbolization portrayal of phenomena by representing computerized geographic data with print or symbols (primarily for data stored in a grid mode).
- Image display/film writer - Photographic-like display of geographic data. May be achieved by 1) photographing screen display or 2) by film writer hardware utilizing computerized data.
- Real time display - Soft-copy display of computerized geographic data on television-like screen (cathode ray terminal).

Tabular Listings

Statistical summaries and categorical listings of environmental data are information products which commonly aid resource managers in their decision making activities. Tabular listings may be accessed from pre-existing listings that have been geocoded and stored, or by producing a listing upon retrieval of specified data categories.

Graphical Display

Other non-map graphical techniques can be applied to portray data in a suitable fashion. Products such as histograms and percentage charts are able to enhance trend-revealing attributes of data when stored within a geographic information system.

Phase V INFORMATION SYSTEM USAGE AND TRAINING

The final and most important phase of an information system is the analysis and eventual decision making based on the information provided. Without such a phase an information system is nothing more than a sophisticated data storage system. This phase needn't always be the final one; decisions often impact the environment in a manner which alters the base data stored within the system, which necessitates a return to the preliminary phases for further interrogation.

Up until now, discussion of geobase information systems have been oriented toward technical and developmental aspects, with little mention of system's uses. As a system, its eventual use is the prime reason for establishing and developing an information system. This aspect must certainly be covered.

The fact that geobase systems deal with the storage, retrieval and management of spatially referenced data from our physical and cultural environment separates its potential usage from other information systems immediately. To really warrant the development of such a system, a user must have a continuing need to obtain spatially referenced information to assist in decision making processes. This would include any agency that requires an inventory of phenomena that vary over space or through time on the earth's surface. Such a user agency could be governmental, industrial or academic in nature.

Besides the institutional distinctions between potential users of geographic information systems, users may be separated by their practical utilization of a system, Applications that immediately come to mind are in the areas of: Regional and urban planning, inventory of services and utilities, storage and referencing of data for modelling spatial phenomena, and, resource management oriented geobase information systems (the focus of this research).

Potential uses of geobase information systems for resource management assessments are numerous. Increased governmental legislation designed to require more stringent monitoring of our natural resources, has placed a strain on resource management activities, at all levels. Increasingly strict monitoring requirements mandated for these resources means that accurate and timely inventories are necessary, with the resulting data easily accessible for eventual management decision making.

Not only does this enhance the need for development of geobase information systems; but, it is also a point in favor of systems that readily incorporate data from remotely sensed resource inventories.

Decision making by agencies concerned with the management of resources tend to be governmentally sponsored and are often involved in a variety of management tasks. Some of these tasks include the assessment of environmental impact, protection of endangered species, determination of resource storage/yeild capacities, etc. All of these tasks require decisions that must be based on current and reliable environmental information. The ability of an efficiently operating geobase information system to supply resource managers this information in a timely, accurate and usuable fashion will impact the quality of their decisions.

It is important that all agency personnel who are involved in the operation and usage of a geographic information system are adequately trained. Adequate training involves the development of a general understanding of why and how the total system operates, as well as a more specific knowledge of areas of specialization for which individuals will be working.

Although a great deal of learning will result from the initial "hands-on" experience in using the information system, formal training is necessary to provide the background and understanding of the operational system use. University research, information systems developers, consultants and other agencies who are experienced with geographic information system usage are capable of providing such training.

SUMMARY

A major step toward assuring improved management of existing land resources is the development of capabilities to systemize, standardize, store, retrieve, compare, analyze, and model geographic data in formats acceptable to a broad array of users. The merging of remote sensing and computers is now sufficiently advanced to make a geo/image-based system economical and powerful enough to be useful. Development of geobased information systems will be facilitated by anticipated changes in image product formats (rectified digital and image products), as well as the recent advances in computer devices which allow for low cost storage of data and low cost processing.

The purpose of the procedures discussed in this manual is to outline the steps necessary to design an information system that will most efficiently meet the information requirements of resource managers, be it a map referencing system or a fully computerized one. When considering alternative information systems, the emphasis should be (1) to insure that the resource inventory methodology developed is germane to user needs and (2) to insure that the procedures adopted are within the user's capabilities to implement and operate the system on a stand alone basis. An analysis of the improved efficiency of a geobase information system utilizing remotely sensed data over conventional resource inventory data handling is a difficult task. By analyzing the derivation of a few of the major information categories in the context of a geobase information system, we can begin to realize the efficiency implications of the system. This section addresses the procedural steps necessary to produce merged, registered data sets, as information sources toward the inventorying of the resource complex.

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CHAPTER 5

TECHNIQUES FOR LAND USE MAPPING FROM REMOTELY SENSED IMAGERY DEVELOPED FROM WATER DEMAND STUDIES IN SOUTHERN CALIFORNIA

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5.1 INTRODUCTION

During the preceeding year, efforts by the Riverside Campus group have been directed toward user-oriented documentation of systems and procedures developed under this grant during the past several years. The documentation is intended for resource management personnel and as an aid in educating resource management students in remote sensing and related techniques.

The process of estimating water demand is different from that for water supply in that physical factors (rainfall, snow melt, runoff) are not primary determinants, Present water demand cannot be estimated reliably from water delivery data because of differences in water source(imported, local) and reporting methods. Water demand can only be determined for both present and future by generally determining a constant representing how the water is used (irrigation, industrial, domestic) and applying some coefficient to account for differences of magnitude within a particular water use class. Water demand estimation essentially becomes a process of land use mapping and mensuration. The procedures documented in this report, while being useful for a variety of mapping tasks, were developed for land use mapping in general and specifically for the particular land use data required for water demand estimation.

The two procedures documented are concerned with extraction of land use information from remote sensing and the display and analysis of that information within the context of a geo-base information system. The primary concern of the former is the ability to reduce the cost of conventional land use survey techniques by utilizing remotely sensed imagery. The concern of the latter is the ability to integrate the land use information into regional (water demand) estimation models with a high degree of accuracy and flexibility.

Techniques for land use mapping from remote sensing are presented in this document as a procedural manual (appendix 5-I). It has undergone several revisions in response to critical reviews. Another manual is being prepared which specifically addresses the details of the computerization aspects of land use mapping. The latter manual has been used in draft form as a classroom lab manual and is now ready to be distributed for critical review to the general public. This report provides an overview of this automated system termed the Spatial Information Processing System (SIPS). Certain of the SIPS programs have been adopted and implemented by the California Department of Water Resources. Full, detailed documentation of SIPS is available upon request.

Appendix 5-II is a reprint of an article published in the prestigious Geographical Review. The article summarizes some of the salient research accomplishments made by the Santa Barbara and Riverside campus groups during the period of this grant. Reprints of the article have been used to inform user agencies of the potential of remote sensing in water demand and have served as an introduction to further contact by agencies and other users.

5.2 PROCEDURAL MANUAL - TECHNIQUES FOR MAPPING LAND USE FROM REMOTELY SENSED IMAGERY

Efforts on the procedural manual have been directed toward improving the manual based upon evaluations received from outside reviewers. A complete draft (reported in the semi-annual report dated December 31, 1976) was submitted to the grant technical monitor and the land use analysts of the Department of Water Resources, Los Angeles Division, for comment (a brief outline of the procedure is listed for reference). One recommendation was to provide some indication of production costs. This has recently been done for a sample map and is reported below.

5.2.1 Outline of Land Use Mapping Procedural Manual

An outline of the Procedural Manual is listed below. The complete text is attached as Appendix 5-I.

The procedural manual for Techniques of Land Use Mapping is divided into three basic sections or phases of operation: 1) Planning Phase; 2) Mapping Phase; and 3) Data Compilation and Presentation Phase.

PLANNING PHASE

Step 1 Define Goals and Objectives
- a. Establish the purpose of the Land Use Map
- b. Establish the Temporal Base

Step 2 Establish a Classification System

Step 3 Establish Accuracy of Parameters

Step 4 Select Data Source(s)

Step 5 Select the Scale and Type of Source Imagery

Step 6 Establish a Base Map

MAPPING PHASE

Step 7 Method of Scale Change, Rectification, and Data Transfer

Step 8 Conduct a Field Survey to Check Interpretation Accuracies

DATA COMPILATION AND PRESENTATION PHASE

Step 9 Select a Method of Final Reproduction

Step 10 Prepare a Clean Copy of the Land Use Map

Step 11 Convert "Clean" Work Map to Machine Format
- a. Machine Digitizing
- B. Procedural Error Editing
- c. Geometric Editing

Step 12 Produce Statistical Tabulation of Land Use Data

Step 13 Produce Final Land Use Map(s)

5.2.2 Evaluation of the Initial Draft of the Procedural Manual

The general response to the draft manual by the two different reviewers was that it does not contain enough specific details. In defense of the manual, we must point out that our original instructions were to limit the manual to no more than twenty pages. To provide the detail recommended, it would require double, perhaps triple, that space. One possible, but not optimal, solution to this problem is to orient the procedural manual as a guideline for the establishment of a land use mapping system and then make liberal use of references to remote sensing manuals (e.g. Manual of Remote Sensing--published by the American Society of Photogrammetry). Another solution is to treat the subject matter in as many pages as necessary while guarding against jargon and verbosity.

The other most frequent criticism of the draft was that many of the statements were vague and should contain additional examples to provide clarification. An attempt will be made to correct any vagueness, and each step of the procedure will be documented with at least one, if not two or three, figures. The figures will illustrate the procedure or contain examples which illustrate the procedure.

5.2.3 Production Costs of Representative Computer Map

One of the factors not included in the draft of the procedural manual was production costs. To provide data to determine production costs, a representative sample map was produced with each step being carefully monitored to determine the time required in both days and hours. The sample region selected was the U. S. G. S. 7 1/2 minute quad sheet containing the area around Redlands, California. The region contains an equal mix of urban and rural areas representing a map production problem of average difficulty. Consequently, regions containing a greater percentage of urban area would have higher production costs, and regions with a greater percentage of rural area would have lower production costs. The following table provides the production hours and actual calendar days required for each production step.

Production Step	Actual Hours	Sessions	Days
Image Interpretation	15	8	4
Field Survey Check	8	2	2
Preparation of Clean Copy	18	8	4
Digitizing (Data Conversion)	31	9	5
Procedural Error Edit	8	4	2
Data Preparation for Computer (Job control prep., etc.)	4	-	-
Geometric Error Editing	30	5	5
	114	36	23

The above list is for labor costs only. Other production costs (i.e. computer time, plotter time, etc.) will be established and included in the final report.

It is noted that the number of calendar days required exceeds the actual hours of labor by twice as many days (8 hours). The type of work involved is tedious and it has been determimed that 2 hours is the average length of time for an individual to work on any one of the production steps before the number of procedural errors exceeds acceptable limits. The alternative, of course, is to have more than one individual participate in the various steps, thus reducing the production schedule for an average map to 15 total calendar days.

The image interpretation was performed by an individual with high expertise and an intimate knowledge of the region. Lesser trained individuals will require more interpretation time. The digitizing and editing procedures were accomplished by an individual with limited experience. Hence, trained personnel would be expected to complete the task with fewer errors and less editing time.

The final report will include a detailed analysis of the costs per number of units mapped, type of map produced, cost per size, as well as other pertinent data.

5.3 OVERVIEW OF SPATIAL INFORMATION PROCESSING SYSTEM

5.3.1 Introduction

The Spatial Information Processing System (SIPS) consists of a suite of related computer programs which can be used to perform selected resource information processing and graphic output tasks. These programs have evolved and are still evolving in response to specific spatial data processing and informational requirements on a project-by-project basis. Most applications for which SIPS has been adapted and implemented rely on remote sensing as a primary data input. The basic goal of SIPS, therefore, has been to utilize geo-base information system technology for processing and enhancing remotely sensed data in resource evaluation programs.

A major design philosophy of SIPS has been the creation of a map compilation and geographic base file handling facility, flexible enough to facilitate the use of the software as specific applications are defined. An attempt has been made to provide for a variety of data input, processing options, and information outputs. It is felt that the key to flexibility is the careful design of data structures and the ability to convert from one data structure to another.

It would be presumptuous for the designer of any geographical information system to assert that all or even a majority of spatial processing functions have been provided. In fact, spatial data processing is an ambiguous concept which is only operationally defined by the activities of practitioners, often in response to rather narrowly defined application criteria. A rigorous definition of spatial data processing tasks (and the creation of a spatial data processing language) is a goal that is yet to be achieved.

SIPS provides the user with many useful data processing capabilities and the flexibility to expand as required. Present capabilities include: 1) map data encoding; 2) geographic data base creation; 3) graphic output in the form of computer generated maps; 4) area calculation and aggregation; and 5) data structure conversion.

Map Data Encoding

A physical map or remotely sensed image can be thought of as a storage device for the geographical data that is present on its surface. The arrangement, selection and graphical qualities of that data convey spatial information. Electronically readable data storage media, such as punched cards, magnetic tape, etc., can be used to store geographical data as well as printed media. In order to electronically store a map there must be some means by which the informational components of the map can be identified. This involves identifying the shape, location and juxtaposition of the geometric entities along with the attributes of those entities--referred to here as map encoding.

There are two fundamental approaches to map encoding, both of which rely on a cartesian coordinate system. The first approach is to consider the map as consisting of a finite set of small, regularly shaped and regularly distributed areas (termed grid cells, resolution elements, pixels, etc.).

Attributes are then assigned to each cell. Points are approximated by single cells, lines are approximated by linearly contiguous cells, and irregular areas are approximated by areally contiguous cells. One distinct advantage to this system of encoding is that the regular geometry allows positional information to be implicit in the data stream. Therefore, no explicit coordinate information need be stored. The Landsat data collection system, as well as many other digital scanner systems, encodes spatial information in this cellular manner. In the case of remote sensor encoding systems, the attribute of each resolution element is a function of the spectral reflectance in a specific wavelength of a cell on the ground.

The second approach to map encoding is to consider the map to be an infinite but spatially bounded set of points (the points become finitely limited given the resolution of a recording device). Geographic entities are then represented by points or connected sets of points which define either a line or a closed boundary condition. Attributes are assigned to points or point groups by association. Since there is no regular and predictable geometry, explicit coordinates must be stored and maintained. The advantage this system has is that highly accurate positional information for most data configurations is available at little penalty in data storage resources. This encoding system usually requires that the map geometry exist on a printed graphics medium before data capture can take place.

Both systems of map encoding have advantages and disadvantages with regard to analysis and mapping. SIPS supports both types of data structures and allows the conversion from one type to another so that the proper encoding scheme (data structure) may be used where it is most appropriate in the data flow.

Geographic Data Base Creation

The simple encoding of map data is normally not sufficient for certain further processing functions to take place. First, the process of map encoding is highly likely to result in errors which may give rise to incorrect map representation or cause data inconsistencies for further processing. Secondly, additional information may need to be generated and merged to produce a data structure useful for graphical and analytic operations. A phase of 'map compilation' is required which involves data editing and processing of the original encoded input data. The output from the map compilation phase is a geographic data base represented by a data structure which is suitable for many applications. SIPS provides for geographic data base creation given either of the two basic encoding systems and alternative geographic data structures.

Automated Mapping

Maps made with the aid of a computer have been in existence for over 20 years. Automated cartography developed along with advances in computer hardware and software. Once the problems associated with encoding and storing a map were resolved, it became apparent that the computer could assist in more than just making maps from spatial data. In fact, the computer could be asked questions about the map it stored. Thus the data organization inherent in automated cartography logically led to the development of geographic information systems. The additional requirement of analytic functions, however, led to the inclusion of additional information in the geographic data base.

The power of complex data structures for geographic information systems must lead to a point of view that the ability to draft maps with the aid of a computer is a by-product of the overall processing effort. That is not to say that care and thought should not be given to the mapping process; rather that mapping software should rely on data inputs which are sufficiently general for the larger overall efforts of geographic information system implementation. Reciprocally, any geographic information system should take advantage of the encoding and data structuring effort to produce maps, where appropriate, with the aid of a graphics output device. Maps are an important means of communicating the informational inputs and outputs of a spatial data processing system to the user. SIPS supports automated mapping on either the commonly available line printer or the generally available x-y plotter. Mapping by the line plotter for map editing and choroplethic displays is provided. Output on the line printer is accomplished with programs which are proprietary. Line printer mapping programs are, however, generally available at very low acquisition and installation cost.

Area Calculation and Aggregation

Two of the questions most often asked of a geographic information system are 'where?' and 'how much?'. The question of 'where' is dealt with via the coordinate system and map outputs. The question of 'how much' implies areal extent and is answered via the coordinate definition of spatial elements from which the areas and linear measures are determined. SIPS allows the user to calculate the area of polygons at various stages of processing. One program, written specifically for area information generation, allows the aggregation of area by attributes associated with each polygon. That is, for each distinct attribute code the total area in the map having that attribute is determined.

Data Structure Conversion

The design of geographic data structures is intimately intertwined with hardware configurations, software architecture, and output requirements. Considerable effort has been oriented toward designing data structures which have the highest information content to storage requirements ratio while satisfying hardware and software performance criteria and analytic requirements. Much of this effort, however, has not been rigorous but is based on the best judgments of the system designers. The philosophy behind SIPS is to allow several different data structures to be used where most appropriate, and to develop algorithms which allow the conversion from one data structure to another. It is felt this approach lends a considerable amount of flexibility in terms of the kinds of data which can be processed.

5.3.2 System Organization

This section describes the software organization and hardware environment in which SIPS has been developed and implemented. Essentially, SIPS consists of a library of stand-alone programs which perform specific functions in a batch processing environment.

SPATIAL INFORMATION PROCESSING SYSTEM

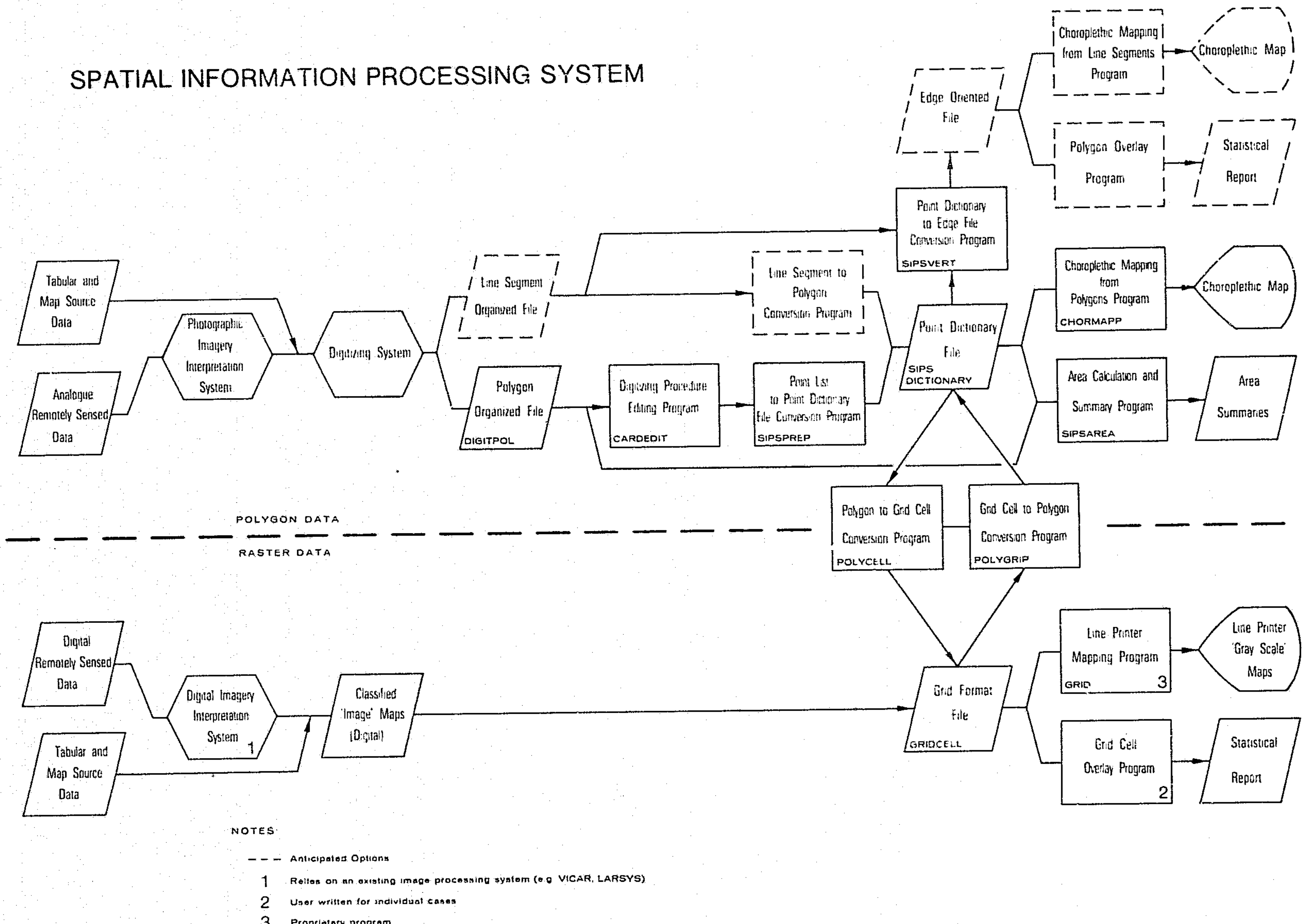

Figure 5-1

5.3.2.1 Software Organization

There are two basic approaches to geographic information system software organization. One approach utilizes the concept of a subroutine library from which the user selects the appropriate modules to perform a specific task. Another approach, employed by SIPS, is to create program packages, with specific functional tasks and a wide variety of options, which exist in a program library as stand-alone executable units. The former approach requires the user to select the appropriate modules for the desired procedure and to assure proper subroutine linkages. The user is therefore required, in the absence of a high level control language, to have considerable programming and system control experience. The latter approach, while incurring slightly more overhead, allows a user to operate the software with no programming experience. Figure 5.1 is a flow chart which depicts the software organization, data formats, and data flow through SIPS.

SIPS software provides the resource planner with several options of input and output. Input may take the form of; 1) thematic maps such as soils, vegetation, etc.; 2) spatially associated tabular data, such as census data; and 3) remotely sensed data, either in a classified line and sample format or as areas delineated from conventional aerial photography. Outputs possible with SIPS are: 1) geographic base files in either cartesian or universal (e.g. UTM, state plane) coordinates; 2) annotated maps; 3) choroplethic shaded maps; 4) area summaries; and 5) frequency histograms.

A short description of each element of the flow chart (Figure 5.1) is given below.

Tabular and Map Source Data

This input includes prepared thematic maps and spatially associated tabular data. It is assumed for polygon data that mapping units are closed polygons which do not overlap and have an associated attribute or set of attributes. For raster data, it is assumed that that the data have been coded in a matrix form or are derived from existing raster data banks.

Analogue Remotely Sensed Data

This data input form includes all data gathered by remotely sensed means and used in an analogue (photographic) format.

Digital Remotely Sensed Data

Remotely sensed data in a digital format, such as that available on Landsat Computer Compatible Tapes, may be input.

Photographic Interpretation System

Remotely sensed photographic format data which are not digital must be interpreted according to a specified procedure. (Appendix 5-1)

Digital Interpretation System

Remotely sensed digital format data which have not been output to film and used in analogue format must be processed and interpreted using a resource oriented image processing system. The image processing system is not a part of SIPS.

Classified Image Map

Input to SIPS from the digital interpretation system should be in the form of a classified image map on magnetic media. The value for each resolution element represents an information class. It is preferable that this image be generalized by the use of a nominal filter.

Digitizing System

Digitizing involves the machine aided encoding of polygon boundaries by identifying the x,y coordinates of the boundary lines.

Polygon Organized File

Digitizer output may be organized according to the point list data structure. That is, each polygon is encoded in sequence with all perimeter coordinates in sequence. Presently, SIPS supports this digitizing procedure only.

Line Segment Organized File

Digitizer output may be organized according to individual line segments with pointers to the left and right side polygons for which the line segment defines a boundary. This type of digitizing is not presently available, but is anticipated.

Digitizing Procedure Editing Program

The CARDEDIT program is used to detect procedural and formatting errors in the digitizer output records.

Line Segment to Polygon Conversion

When line segment digitizing becomes available, a utility program will be developed which will perform a conversion from a line segment to a polygon data structure.

Point List to Point Dictionary File Conversion

The SIPSPREP program converts from a point list to a point dictionary file.*

Polygon to Grid Cell Conversion Program

The POLYCELL program converts from a polygon data structure to a grid (raster) format.

Edge Oriented File

The topologically oriented data structure employs the concept of the winged edge which gives branching information about line segments and is useful for polygon search and cycling as well as many other analytical purposes.

Point Dictionary to Edge File Conversion Program

The SIPSVERT program performs the conversion from a polygon oriented data structure to an edge oriented topological data structure.

Point Dictionary File

The SIPS Dictionary file is the primary polygon data structure used by SIPS. It is based on a sequential list of pointers to polygon coordinate values for each polygon.*

Grid Cell File

The standard SIPS format for input and output of grid cell structured data is the GRIDCELL file. It basically consists of a record for each line of data with the value in the record as the z coordinate and the position within the record as the sample coordinate.

Grid Cell to Polygon Conversion Program

The POLYGRIP program converts from a grid cell (raster) file to a SIPS Dictionary file.

Choroplethic Mapping From Line Segments Program

This anticipated program will produce choroplethic maps from a winged edge file. This will allow for dropping boundary lines between polygons which have the same mapping classification.

Polygon Overlay Program

The polygon overlay program, when written, will allow the boolean combination of two polygon data sets.

Choroplethic Mapping From Polygons Program

The CHORMAPP program produces area aggregation by pre-set classification levels, histogram output, and choroplethic maps in either shaded or annotated form.

Area Calculation and Summary Program

The SIPSAREA program produces a listing of total area for each unique polygon attribute in several selectable reporting units.

*For an explanation of this data structure terminology, see Peucker and Chrisman, "Cartographic Data Structures", The American Cartographer, Vol. 2, No. 1, April 1975.

Line Printer Mapping Program

The GRID program is used to display grid cell formatted data on the line printer. This program is not an integral part of the SIPS system because it is proprietary.

Grid Cell Overlay Program

The grid cell overlay program is a user written program for combining two or more grid cell structured data sets. These programs are easily written with a minimal amount of programming expertise.

5.3.2.2 Hardware Configuration

This section describes the computer hardware systems around which SIPS has been developed. There are three distinct processing systems used by SIPS; 1) the general purpose processing system; 2) the digitizing system (cartographic data input); and 3) the plotting system (cartographic data output). The general purpose processing system is the campus computing facility at U. C. Riverside. The other two systems are operated and maintained by the Department of Earth Sciences at U. C. Riverside.

General Purpose Processing System

This computing system consists of an IBM 360-50, supporting batch processing only, with the following specifications:

- MVT-OS operating system
- 8 series 2314 disk drives
- 3, 800 BPI, 9-track tape drives; 1, 7-track tape drive
- 1 megabyte of memory
- other standard peripheral devices

Digitizing System

The digitizing system is schematically represented in Figure 5.2. Output is normally to the keypunch as on-line editing capability via the NOVA 1200 is presently limited.

Plotting System

Although the campus computing facility supports a CALCOMP drum plotter, the plotting system used by SIPS consists of a 42 x 72 inch, four pen, flatbed plotter. This plotter is not an incremental type, but a vector type. Plot commands are executed based upon an angle and distance input (polar coordinates). The maximum number of angles that can be differentiated is 2^{19}. Maximum speed is 8 inches per second. Plotting resolution is .001 inch. Plot tapes are normally written at the campus computing facility and read off-line by the plotter system tape drive. A NOVA 1200 with 20K bytes of memory serves as the plotter controller. Figure 5.3 is a schematic representation of the plotter system.

Appendix 5-I

TECHNIQUES FOR MAPPING LAND USE FROM REMOTELY SENSED IMAGERY

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University of California, Riverside

Procedural Manual
NASA Grant #NGL 05-003-404

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TECHNIQUES FOR MAPPING LAND USE FROM REMOTELY SENSED IMAGERY

PREFACE

Remote Sensing researchers of the Department of Earth Sciences, University of California, Riverside have conducted extensive research involving land use mapping over the past several years. From this research, certain techniques and production steps have evolved. The procedures have been implemented, tested, and refined as a result of work performed for the National Aeronautics and Space Administration (NASA) under a four-campus research grant (NGL 05-003-404).

It is believed that many agencies and organizations conducting studies involving land use mapping can profit from our experience. Therefore, this manual is presented by outlining the various production steps that are utilized in producing a land use map. A question arises as to how brief, or how extensive the description of each step should become. Because it is the intent to acquaint the directory of operations (e.g. the Planning Director) with the essential elements of the procedures and techniques as well as provide the actual production personnel with a procedural outline, it was decided to limit the extent of explanation of each step. Therefore, the manual is written with the intent that the actual production worker who must do the photo-interpretation or operate the computer programs associated with the map production will have access to more detailed manuals and have had specialized training.

The complexities of the field of remote sensing is evidenced by the size of the Manual of Remote Sensing (2 volumes). Published by the American Society of Photogrammetry in 1976, the Manual of Remote Sensing contains the specialized details of interpreting the various categories of the earth's resources. It is anticipated that workers actually involved with the detailed photointerpretation will be familiar with the Manual of Remote Sensing.

This procedural manual addresses the mapping of land use in particular, but the procedures are equally applicable to a variety of Earth resource mapping objectives. A list of some other types of mapping categories may be found in the matrix of Figure 1.

SENSOR EVALUATION IN SOUTHERN CALIFORNIA

(Assumes Mid-Altitude Platform)

		Ultraviolet	Visible				Near IR		Intermediate IR		Microwave			
		Scanner .29-.5	Absorption Spectroscope	B/W Film	TV Camera	Color Film	B/W	Color	Scanner 3.5-5.5μ	Scanner 8-14μ	Side Looking Radar Scanner (K band)	Scatterometer 13.3 Ghz	Passive Radiometer 9.3+15.8Ghz	Passive Imager 19.35Ghz
Land Use	Rural	3	4	2	2	2	3	1	3	3	2	4	4	2
	Urban	3	4	2	2	2	3	1	3	2	2	4	4	3
	Other	3	4	2	3	2	3	1	3	3	3	4	4	3
Transportation	Network	3	4	2	2	2	3	2	3	2	2	4	4	3
	Surveillance	3	4	3	2	3	3	2	3	2	2	4	4	3
	Volume	4	4	3	2	3	3	3	3	3	2	4	4	3
Hazard Prediction	Forest Fire	3	3	3	3	2	3	1	3	2	3	4	4	3
	Flood	3	4	2	3	2	3	2	3	2	2	4	4	3
	Earthquake	3	4	3	3	3	3	3	3	3	3	4	4	3
Land Forms	Pattern	3	4	2	2	2	2	1	2	2	2	4	4	2
	Relief	3	4	2	3	2	3	2	3	3	3	4	4	3
	Structure	3	4	3	3	2	3	2	3	2	2	3	3	3
Shore Areas	Form	3	4	2	2	1	2	2	3	2	2	4	4	2
	Change	3	4	2	2	2	2	2	3	2	2	4	4	2
	Energy	2	2	4	4	4	4	3	2	2	3	3	4	1
Vegetation	Type	3	4	3	3	2	3	1	3	3	3	3	3	3
	Distribution	3	4	2	2	2	2	1	3	2	2	4	4	2
	Health	3	4	3	3	3	2	2	3	2	3	4	4	4
Soil	Class	3	4	2	3	2	2	2	3	3	3	3	4	3
	Distribution	2	4	2	2	2	2	2	3	3	2	4	4	2
	Surface Moisture	3	4	3	3	3	3	2	3	2	2	2	3	3
Water	Drainage Pattern	3	4	2	2	2	2	1	2	2	2	4	4	3
	Ground Water	3	4	3	3	3	3	3	3	2	3	3	3	3
	Sea State	3	4	3	3	3	3	3	3	3	2	4	3	2

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Figure 1: Matrix of earth resources mapping objectives with sensor evaluation. This matrix may be used in STEP 1 (Planning Phase) to establish the purpose and objective of a proposed land use mapping project. The mapping techniques described in this procedural manual apply to many other types of earth resources in addition to land use. The lefthand column in the chart lists potential categories of earth resources that planners may wish to map to aid in their analysis work and subsequent management decisions. The various bands of the electromagnetic spectrum are shown on the top scale. The sensors that will image each of these electromagnetic bands are listed as column headings. The usefullness of each of the sensors to image the respective earth resource is shown in the matrix on a scale of 1 to 4 representing good (1) to bad (4). Note that the color film in the fifth column will image the natural color a person normally sees from the visible range. The color (film/print) in the seventh column will image the invisible near infrared range and is usually reproduced in false color red on film or print. This latter color infrared (CIR) film is recommended in the text for most land use mapping.

A. INTRODUCTION

The production of a land use map involves carrying out a series of tasks which result in an end product of pre-defined quality. The quality may be only a simple sketch map of a designated area with written or coded notations of the land use. On the other hand, the quality may be a very elaborate four color shaded map prepared by an automated drafting machine. Obviously, the tasks will vary in detail and effort according to the desired quality of the end product. Most land use mapping efforts have general tasks in common. These include planning, data acquisition and mapping, and data compilation and display. Because the general tasks normally follow one another chronologically, they may be referred to as 'phases'.

Before any land use or thematic mapping is begun, a planning phase should be carried out in which objectives are defined and quality control parameters are established. The objective may be to provide data from which the water demands of the region can be predicted for the next thirty years. Such an extensive objective would require accurate detail of boundaries of land use because land use is the driving parameter in the water demand model. Likewise, the quality of the final product (map display and statistical compilation) should be of such quality that it can be reproduced and utilized in publications that have a lifetime of several years. The objectives of an urban planner may be for a land use map to be used in a general plan to assist in making zoning decisions. To insure the final product meets the pre-defined objective, the planning phase must include consideration of how, where, when, and what type of information is to be acquired.

The second or production phase includes data acquisition and mapping. Information is transferred from the actual site by either a field survey or from remotely sensed data to a draft map. Normally, this involves categorization of the data (i.e. housing, industry, agriculture, water areas, etc.), scale change (image scale may be 1:130,000 and final desired scale be 1:12,000), and positional control relative to a planimetric base map (area calculations require that points or intersections be located on the map with sufficient accuracy that computed map area is equal to actual ground area).

The production of a planimetrically correct draft land use map represents the completion of the production or information phase. However, two major tasks remain in order for the work to be useful to the planner. First, the map must be suitably prepared for presentation and its readability enhanced (e.g. an inked final copy with color or shading either manually or automatically drawn), and second, the map information must be compiled so as to answer the question of "how much?" as well as "what?" and "where?" (e.g. How many hectares of agriculture and where is it located?) Area measurements and summaries are therefore a requisite part of any major land use mapping effort. This is termed the data compilation and presentation mapping phase.

B. PLANNING PHASE

Step 1: Define Goals and Objectives

a. Establish the purpose of the Land Use Map.

The decision to be made in each phase is totally dependent upon the purpose or final use of the map. If the map is to be used to estimate water demands, it will dictate to what detail land use must be classified. (e.g. Can housing be grouped as one area, or does it need to be categorized into single and multiple residential, transient, rural?) For water demand, housing as a general classification may be sufficient, but for the city or county planner who may want to use the map for establishing a zoning ordinance, the map must be in greater detail. Figure 1 provides a matrix of possible Earth resource mapping objectives that may be accomplished using remote sensing.

b. Establish the Temporal Baseline

The prime reason for the recurring need to map land use is rapid change. If the data needs to be acquired for a large area at an instant of time - such as an agricultural crop inventory - the acquisition problem is greater than if it is for a slowly changing central business district. The large agricultural area may require an instantaneous image taken at a particular time of the growing season. The data for a small unchanging urban area may be adequate from imagery taken a year ago.

Land use data may be obtained by means of ground survey or aerial survey. For a large land use mapping project, the time required to complete a survey may be months, even years. The time lapse can lead to a situation where one portion of a study area is not temporally compatible with another portion. Aerial surveys provide data at essentially a point in time, resulting in temporal consistency throughout the study area.

In using aerial survey for data collection, there are several problems in establishing the time base. These considerations relate primarily to the type of platform. If the user is able to contract privately for this service, the only limitations are atmospheric clarity and suitability for flying at the desired time. However, if pre-existing imagery (usually provided by a governmental agency such as NASA) is to be used, the user must be prepared to accept the dates of applicable coverage. The most continuous coverage is provided by Landsat imagery: at least every 9 days, all of which may not be usable. LANDSAT D will provide betterresolution than the previous LANDSAT satellites, and the new data may provide a useful tool for gross urban or large scale land use mapping applications. High altitude aircraft imagery does not provide synoptic coverage, but large areas have been imaged and may provide the needed coverage. The U. S. Geological Survey EROS Data Center provides a computer search of available governmental coverage from a variety of sensors. This search may be performed by specifying latitude and longitude coordinates for either a point or rectangle (U. S. G. S., 1976).

Step 2: Establish Classification System

Land use has a variety of real-world expressions. Theoretically, it would be useful to attempt to identify each of these expressions unambiguously. However, such effort would require gathering and handling an inordinate and superfluous amount of data. For convenience, land use expressions are categorized and classified.

One does not classify land use to any degree of specificity which is more than is required for operational applications. However, one does not want to be so general as to lose information which is essential for operation and planning purposes. The end purpose of the land use information must dictate the classification system. Because most land use classification systems are hierarchical in nature, the specificity or refinement of the system is usually indicated by needs of the user.

Four levels of land use classification types are generally recognized. In agriculture, a fifth level has been developed to specify certain types of plants grown for food. An example of the hierarchical structure to four levels is provided in Table 1. Figure 2 contains three classification systems with different philosophies underlying their organization.

Table 1

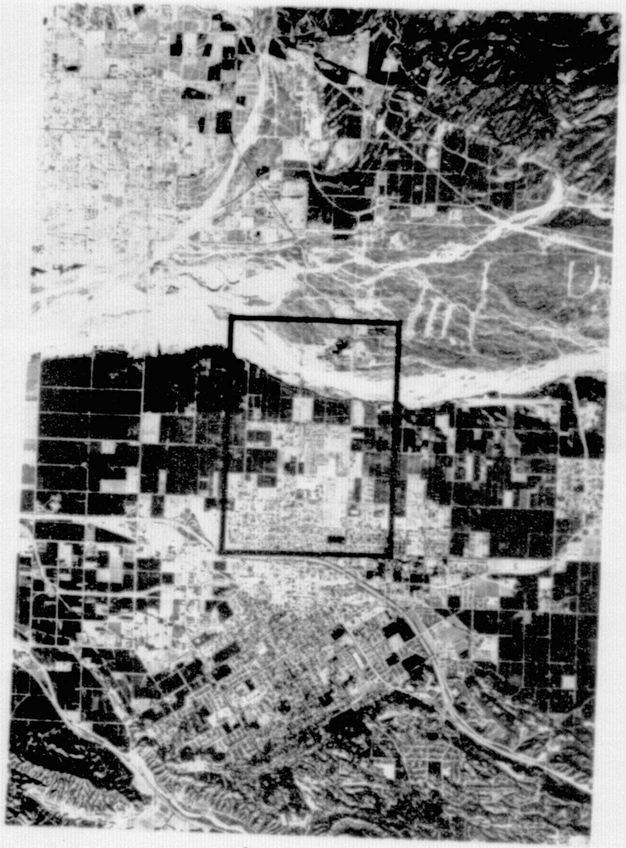
Excerpt from land use classification system showing hierarchical structure

(San Diego County, C.P.O., 1968)

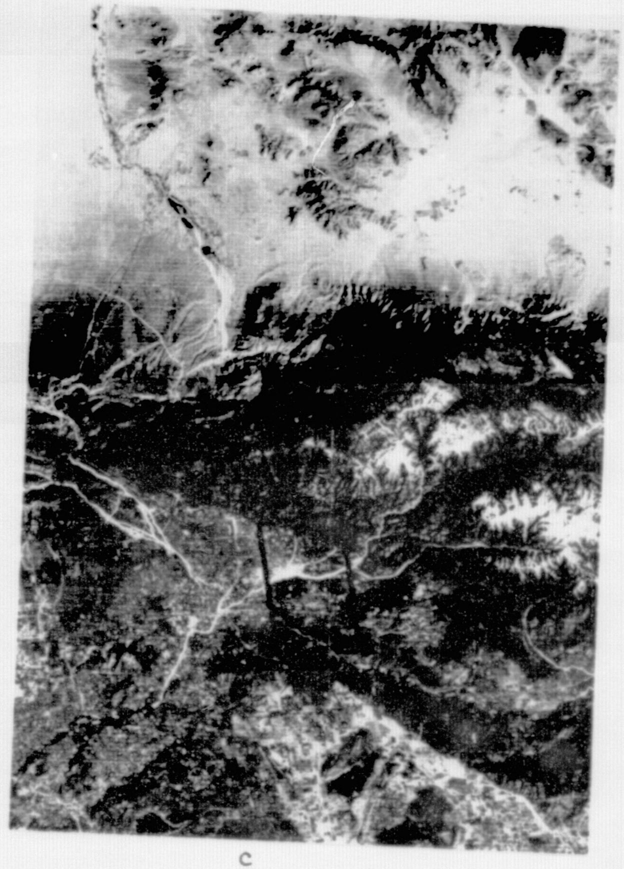
First level.......	7000	Cultural, Entertainment, and Recreational
Second level...........	7200	Public Assembly
Third level....................	7210	Entertainment Assembly
	7220	Sports Assembly
Fourth level............................	7221	Stadium and Coliseum
	7222	Arenas and Field Houses
	7223	Race Tracks, (Animal)
	7224	Race Tracks, (Auto)

Resource managers who must work with both urban and rural regions, such as water resource or forest managers, prefer a dichotomous classification system (urban/rural) with hierarchical breakdowns under those two headings. Interpreters extracting general land use data from high altitude aircraft and satellite imagery often create a system that fits what can be observed from the image. This latter remote sensing approach, if followed rigorously, has the tendency to make the analysis of the data more difficult for planners who are use to a more planner oriented classification system. Therefore, either the interpreter or the user must modify his mode of operation.

a



b



c

Figure 2: Three scales of imagery of the Redlands, California area comparing ground resolutions and area of coverage for the different scales of imagery. These three images illustrate how the scale of imagery can be selected as suggested in STEP 5. The scales of the images are: a - 1:28,000; b - 1:110,000; and c - 1:880,000 (e.g. 1 inch on the image represents 28,000 inches on the ground or 0.44 miles). The ground resolution of the target category (e.g. single family housing or multiple family housing) will determine the scale imagery required. The apartments just above the orange grove at the bottom of image a can be differentiated from the single family dwellings in the surrounding areas. In image b the apartment units can be detected in the same area only because we could detect them through the higher resolution of image a. We cannot detect the apartments in image c. Image c , however, will permit us to differentiate between urban areas, agricultural, river washes, forest land, and desert. Images a and b were taken by a NASA U-2 high altitude aircraft platform on December 1, 1975. Image c is a NASA Landsat I satellite image taken February 22, 1975. All three images are typical of the government imagery available from the U. S. G. S. EROS data center in Souix Falls. South Dakota.

TABLE 2a

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LAND AND WATER USE CLASSIFICATIONS

UCR CLASSIFICATIONS Code	Title	DWR EQUIVALENT CLASSIFICATIONS Code	Title
1	LIVING AREA		RESIDENTIAL (URBAN & RECREATIONAL)
11	Medium Density Urban (Single)	UR	Urban Residential
12	High Density (Multiple Units)	UC 2/RR	Motels, Urban & Resort
		UC 4	Urban Commercial (Apts & Barracks)
14	High Density (Mobile Homes)	UR	Urban Residential
15	High Density (Transient Lodge)	UC 4	Urban Commercial
13	Low Density (Urban Estates)	UR	Urban Residential
16	Low Density (Rural Dwelling)		
17	Low Density (Recreation Unit)	RR	Recreation Residential
2-3	INDUSTRIAL (Manufacturing)		URBAN INDUSTRIAL
21-27	Light Industry	UI 1	Manufacturing
28-34	Heavy Industry	UI 61-12	Sawmills, Oil, Paper, Meat, Steel, Food
4	TRANSPORT & UTILITIES		
41	Railways & Rail Terminals	UI 3	Storage & Distribution
42	Motor Transport Facilities		
43	Aircraft Facilities		
44	Marine Craft Facilities		
45	Highways and Roads	UV 4	Urban Vacant, Paved
46	Automobile Parking	UV 4	Urban Vacant, Paved
47	Communications	UI 3	Storage & Distribution
48	Utilities (water, gas, elec. sewer)	UI 3	Storage & Distribution
5	COMMERCIAL (Trade)		URBAN COMMERCIAL
51	Wholesale Trade	UI 3	Storage & Distribution
52-58	Retail Trade	UC 1	Misc. Establishments
6	SERVICES		
61-66	Commercial & Professional	UC 1	Misc. Establishments
67	Government		
68	Education	UC 6	Schools
69	Social	UC 5	Institutions
7	CULTURAL, ENTERTAINMENT, REC		
71	Cultural	UC 7	Auditoriums, Theaters, Churches
72	Public Assemblies	UC 7	Auditoriums, Theaters, Churches
73	Amusements	UC 7	Buildings & Stands w/race tracks, etc.
74	Recreational Activities	UC 7	Football Stadiums, sports parks
75	Resorts & Camps	RT	Camp & Trailer Sites, Recreational
76	Parks and Golf Courses	P	Parks, Recreation
8	RESOURCES		
81	Agriculture	A	Agriculture
81.4	Dairies	A	
82	Agriculture Related	S	Semi-Agriculture
83	Forestry Activities		
84	Fishing		
85	Mining	UI 2	Extractive Industries
9	UNDEVELOPED		URBAN VACANT/NATIVE
91	Land	UV-1	Unpaved, Urban Vacant
92	Forest	NV	Native Vegetation
93	Water (Incl Dry Channels)	NR	Riparian Vegetation
		NW	Water Surface

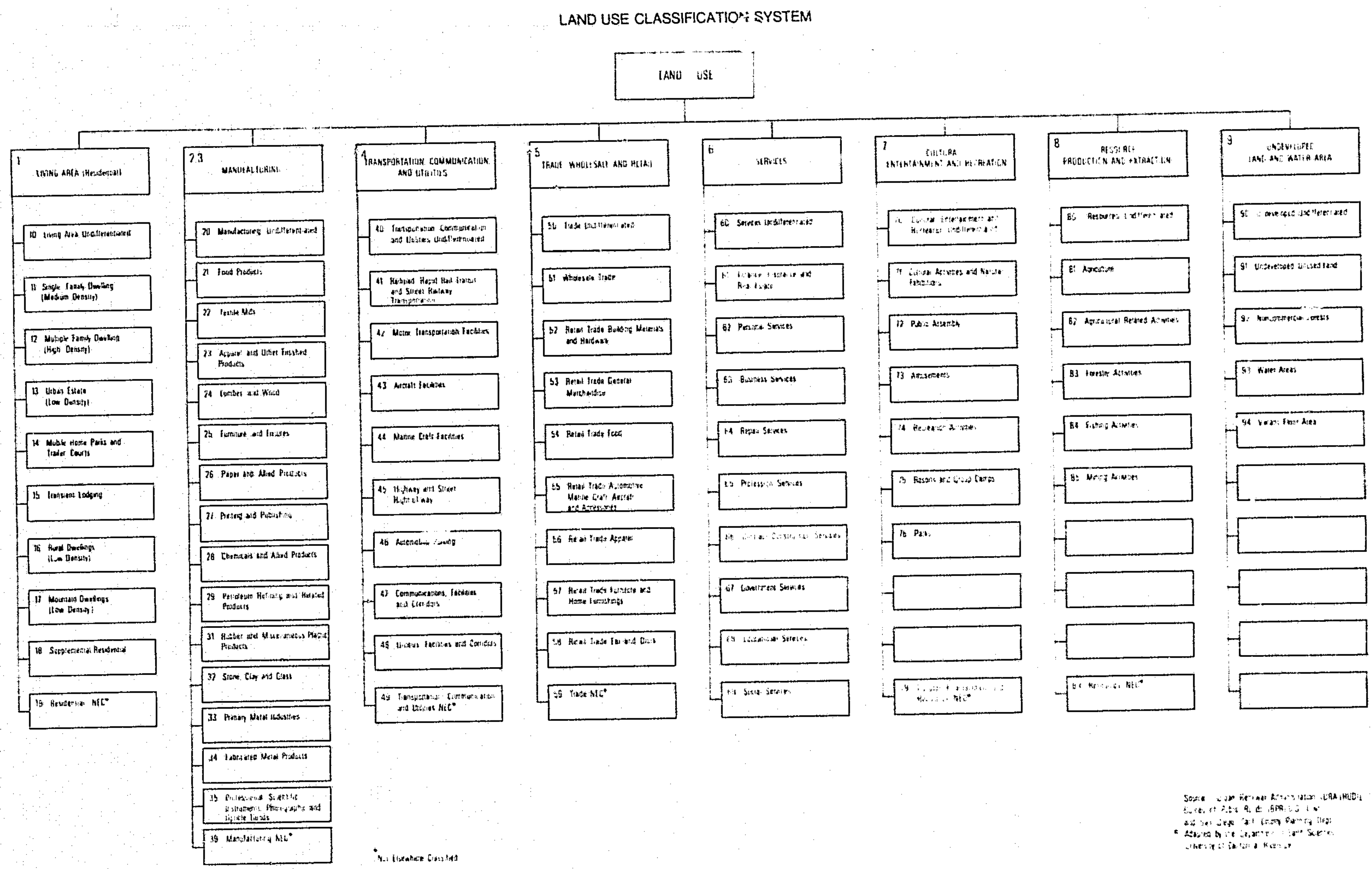
TABLE 2b

LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA

LEVEL I	LEVEL II		ALPHA CODE
1. Urban and Built-up Land	11.	Residential	Ur
	12	Commercial and Service	Uc
	13	Industrial	Ui
	14	Transportation, Communications, and Utilities	Ut
	15	Industrial and Commercial Complexes	Ucc
	16	Mixed	Um
	17	Other	Ut
2 Agricultural Land	21	Cropland and Pasture	Ac
	22	Orchards, Groves, Vinvards, Nursaries, and Ornamental Horticutural Areas	Aor
	23	Confined Feeding Operations	Acf
	24	Other	Ao
3 Rangeland	31	Herbaceous Range	Rh
	32	Shrub-Brushland Range	Rs
	33	Mixed	Rm
4 Forest Land	41	Deciduous	Fd
	42	Evergreen	Fe
	43	Mixed	Fm
5 Water	51	Streams and Canals	Ws
	52	Lakes	Wl
	53	Reservoirs	Wr
	54	Bays and Estuaries	Wb
	55	Other	Wo
6 Wetland	61	Forested	Wlf
	62	Nonforested	Wln
7 Barren Land	71	Salt Flats	Bsf
	72	Beaches and Mudflats	Bbm
	73	Sandy Areas Other than Beaches	Bs
	74	Bare Exposed Rock	Br
	75	Strip Mines, Quarries and Gravel Pits	Bsm
	76	Transitional Areas	Bg
	77	Mixed	Bm
8 Tundra	81	Shrub and Brush Tundra	Ts
	82	Herbaceous Tundra	Th
	83	Bare Ground Tundra	Tb
	84	Wet Tundra	Tw
	85	Mixed	Tm
9 Permanent Snow and Ice	91	Permanent Snowfields	Ps
	92	Glaciers	Pg

(Source: U.S. Geological Survey Professional Paper 964)

Table 2c



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The primary concern in constructing a land use classification system to be used with an image data base is to provide at least some level of classification for all necessarily detectable land uses. Land use types which are to be differentiated but are non-detectable from imagery must be identified from some other data source. Fortunately, data from multiple sources are easily mixed so that the best land use information can be used.

A two level classification system is quite feasible from most remote sensing imagery. In many cases (e.g. low altitude imagery) a third and sometimes fourth level can be detected. Unless there is some overriding reason (e.g. agricultural crop mapping), it is recommended that a classification system be limited to the second level for most categories. In some instances where the objective demands it, a third level may be possible and desirable (e.g. housing categories; single family residential, multiple family, estates, rural low density housing).

Step 3: Establish Accuracy Parameters

To save time, effort, and maintain a certain degree of uniformity, throughout the mapping project it is necessary to establish resolution, classification, and positional accuracies. Resolution refers to the smallest area on the ground that is to be mapped. Classification accuracy refers to what hierarchical level different categories of land use will be listed. Positional accuracy refers to the relation of delineated boundaries with some specific geographic reference system relating to actual physical location on the ground.

a. Resolution Accuracy

Resolution accuracy refers to the smallest area on the ground which is considered to be a distinct land use and is to be delineated as such. For example, if the resolution accuracy is one acre, any differentiable land use with an areal extent of less than one acre is not mapped but is considered to be an integral part of the surrounding use.

Resolution accuracies may be applied differentially but systematically throughout the study area. In regional applications, urban areas are often mapped at a greater resolution than the surrounding rural areas. Decisions as to whether or not to map linear features are usually determined by linear distance of the feature cross section, such as the width of a road, as opposed to actual areal parameters.

b. Classification Accuracy

Classification accuracies describe the ability to correctly determine the land use according to the chosen classification system and the hierarchical level within that system. That is to say, if a classification accuracy of 90% were established, for any sample of delineated parcels, the assigned land use should be correct for at least 90% of the parcels. Because the assignment of land use to a classification system element is sometimes a value judgement, this accuracy term is not precisely measurable. It should be established though and is often included in private contracts as the primary means of determining accuracy. A reasonable accuracy from remotely sensed data is 95% if ground survey checking is used concurrently with the photo interpretation.

c. Positional Accuracy

Position refers to the relation of delineated boundaries with some specific geographic reference system. If the land use map will be used to summarize land use by area measurement and the accuracy of results is to be within 2% of reality, then a base map that is accurate to 2% tolerance is required. The United States Geological Survey publishes maps certified to a ground accuracy of 40 feet (12 meters). Base maps with this accuracy will provide adequate control to enable area measurements acceptable to most planners. However, if a generalized map is being prepared to assist in zoning or management decisions that do not require areal measurements, or is not to be registered with other map data, then more distortions may be acceptable.

Step 4: Select Data Source

Land use data may be obtained by either actual inspection on the ground (field survey) or from remotely sensed imagery, or by a combination of the two. Remotely sensed imagery is available from many government and private film libraries or may be contracted for from private sources. A little time spent at the beginning of the project to determine the availability of imagery for the region under investigation may pay off in savings of both time and money. Use of available imagery may require a compromise in some of the planning parameters, but the savings may justify the use.

Today we have the advantage of diverse platforms that provide several types of images for multiple dates or time periods. The aerial image (Figure 1b) enables large regions (e.g. the California Desert with 25 million acres, 10 million hectares) with poor accessibility to be mapped with a high degree of accuracy. Data for land use mapping from remotely sensed imagery has become a normal acquisition method and the field survey is used for accuracy checking. Selected scale imagery can be acquired that will fulfill most of the data requirements to a third level of calssification and sometimes even to lower levels. However, there are limitations. For example, if the classification system requires knowledge of the composition of types of businesses in high rise buildings in the central business district, then imagery is not the total solution.

The two methods of data acquisition (aerial imagery and ground survey) used in combination present the most complete solution to land use mapping. Imagery can provide the basis for boundary determination as well as establishing land use to the second and third levels of classification. To verify questionable areas of interpretation, it is essential to perform a ground survey. Any urban detail, such as distinguishing between retail and wholesale trades (which are not detectable from imagery), must be resolved from the field survey.

Step 5: Select the Scale and Type of Imagery

The ground resolution (dimensions of the smallest object on the image to be detected) desired and the target being imaged usually dictate the scale and type of imagery to be obtained. Because of the contrast found on some imagery (such as color infrared), a lower resolution may be possible. If vegetation detection is a prerequisite, color infrared film is suggested. However, for some types of resource mapping, other films are desired. The ramifications of film type and resolution are too extensive to elaborate in this discussion. The reader is referred to the American Society of Photogrammetry's Manual of Remote Sensing for detailed information on the subject. Figure 2 shows three different scales of NASA imagery and gives an indication of the resolution obtainable from each.

a. Scale and Ground Resolution

The level of classification will determine the needed ground resolution. One factor to keep in mind when selecting imagery, whether from a library or special aerial survey, is that the finer the resolution, the greater will be the acquisition cost (e.g. a scale of 1:3,000 costs at least 10 times that of a scale of 1:30,000!!). It is often possible to work with imagery at less resolution than might otherwise be thought. As an example, a project may be established to ascertain beach attendance on a Sunday afternoon in the summer. The first reaction is to acquire imagery that can detect a person walking on the beach, which would require ground resolutions of less than .3 m (1 foot). Obtaining this type of resolution would normally require the imagery to be at a scale of between 1:2,000 and 1:3,000. Perhaps the beach attendance could just as well be established by counting nearby parked cars. To detect an automobile, a ground resolution of only 3 m (9-10 feet) is required. Imagery obtained at a scale of 1:24,000 can easily provide this information. The cost of the smaller scale imagery would be considerably less since the same format imagery at a smaller scale can image a much larger land area and thus requires fewer frames of film. Again, note Figure 2 showing NASA imagery at three different scales and the relative coverage of each.

Another scale consideration relates to the rectification required to produce a planimetric map (e.g. all points on the map are located in true distance and angular relationship to each other relative to a given base). Having the original image produced at the same scale as the base control map may provide a cost savings in the data transfer process. The United States Geological Survey publishes a topographic series of maps at a scale of 1:24,000 that provides excellent planimetric control. Imagery acquired at the same scale enables the transfer of data simply by overlaying the image on the base map. When selecting imagery from the government libraries, it may be necessary to compromise on the scale and ground resolution to take advantage of the cost savings provided by the advantage of not paying for original acquisition costs.

b. Platform

The selection of the platform utilized to acquire the imagery will have been pre-established if the imagery is being acquired from government sources. Some selectability is available if new imagery is being acquired from a private aerial survey company. Low altitude and some medium altitude aircraft flights are available from private sources. High altitude aircraft flights and satellite platform data is available from government sources only. The definition of platform altitudes and attendant scales for purposes of this manual are:

PLATFORM ALTITUDE		RELATIVE SCALE NORMALLY OBTAINED
Low Altitude	(5,000 - 15,000 ft.)	1:1,000 to 1:12,000
Medium Altitude	(15,000 - 45,000 ft.)	1:12,000 to 1:30,000
High Altitude	(50,000 - 70,000 ft.)	1:30,000 to 1:250,000
Satellite	(100 - 600 n mi)	Smaller than 1:250,000

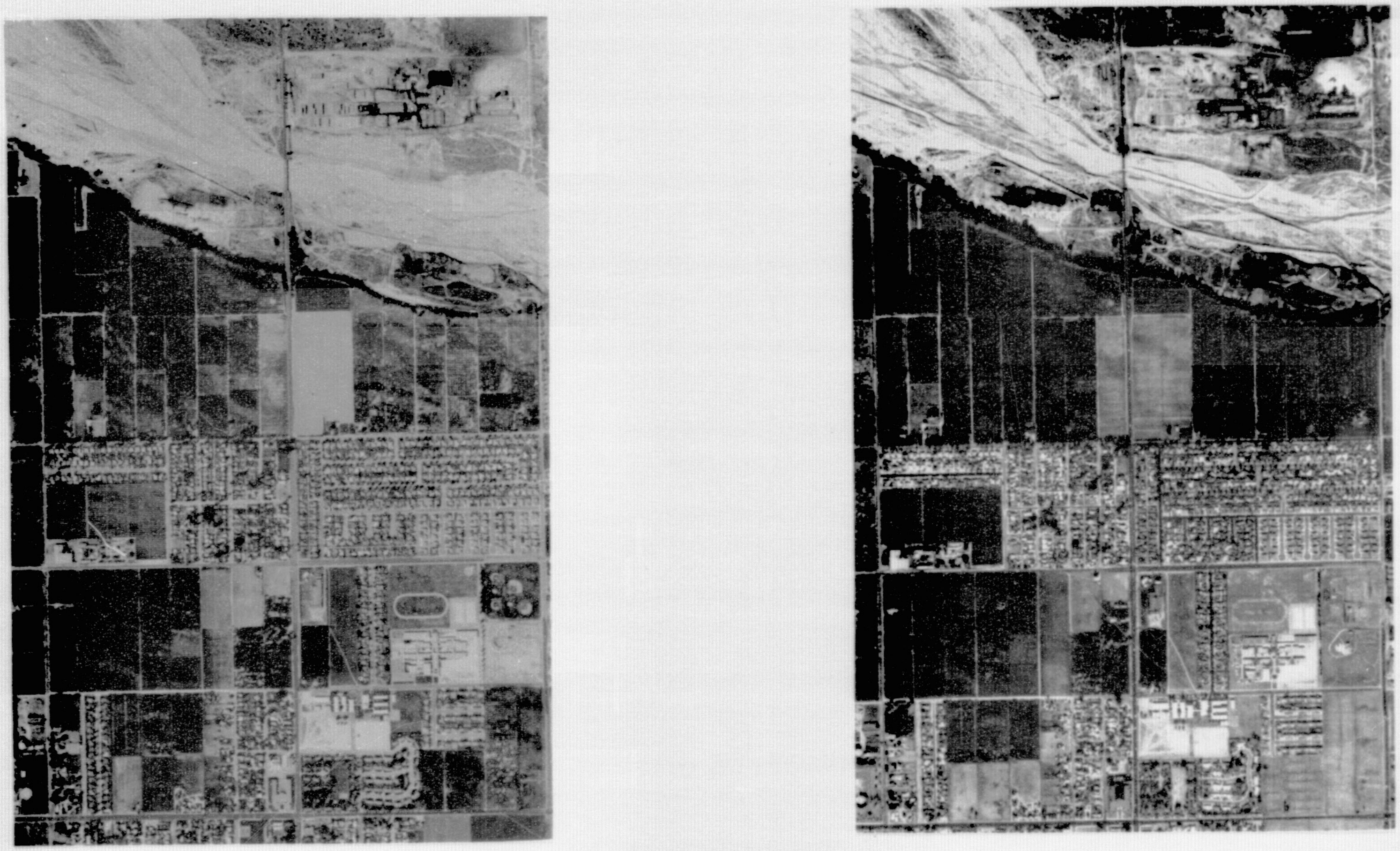
c. Format and Type of Imagery

Imagery available from government sources includes various formats and types of imagery. Film or print formats range from 70mm "chips" to 9" x 9" aerial roll film format. Prints, negatives or positive film, are available in black & white, natural color, color infrared, or thermal infrared as well as film produced from a few other types of sensors (Figure 3). In addition, multispectral imagery is available in both digital and film formats. If the vast collection of imagery held by government sources cannot meet individual requirements, then a locally contracted survey must be planned. Under the latter circumstances, the planner must still decide the type of imagery and format considered in light of their costs.

The sharp contrast afforded by Color Infrared (CIR) imagery is a big factor in selecting it for land use mapping. Although it costs approximately 4 times as much as black and white film, it provides many surrogates to make the interpretation process faster and thus saves costly man hours which more than pay for the added cost of the film. Two particular examples stand out in urban land use mapping. The typical single family residential district becomes very distinct with the uniform false color red of tree-lined streets intermixed with the dark gray of shingled roof tops. The Central Business District (CBD) becomes readily definable by its contrasting blue-gray signature of the stark buildings lacking any red that might indicate vegetation such as trees. Even the few trees being added to renovate sections of the CBD show an insignificant redness against the predominance of the larger buildings. CIR likewise shows a sharper contrast of features as opposed to natural color (Figure 4a, and b).

The complexities of the use of various types of films and platforms prohibit a detailed discussion in this procedural manual. Because of the complexities of the interpretation process (and its associated pre-planning), the American Society of Photogrammetry has published a two volume series entitled Manual of Remote Sensing (ASP 1976). As stated in the preface, it is anticipated that an agency planning to develop a land use mapping system or employ some of the techniques described here has become aware of the

Figure 3: Photo-interpreter selecting the type of imagery and format size (STEP 4). Remotely sensed imagery is available from governmental sources in many forms as indicated in the sensor types listed in figure 1. It may be available as film transparencies in black and white (B/W), color, color infrared, or as prints. Scanned image data may be available in many forms and sizes including magnetic tape storage which may be further processed into image data by the user with such capabilities. If the imagery from government sources is not suitable due to timeliness, availability, resolution, or other reasons, then a private aerial survey may be contracted to rpovide the exact type of imagery desired.



a b

Figure 4: Comparison of the contrast between natural color prints and color infrared prints. (STEP 5). False color infrared imagery is recommend for most land use mapping objectives. The sharp contrast of the false infrared vegetation in image b enables the interpreter to detect the boundaries between different categories of land use with greater ease. The color infrared return of the trees along the residential streets as well as the 'red' grass lawns are typical residential surrogates. The grey roof of the U-shaped school administration building at the bottom of the image stands out against the 'red' grass in image b, much more distinctly than in image a. The growing status of the orange groves are more evident in image b.

complexities of photo-interpretation through various courses or through study of the Manual of Remote Sensing or similar technical manuals.

Step 6: Establish Base Mapping System

The choice of a base map to be used in controlling the drafting of the work map is dependent upon the required accuracies. The base map should contain cultural details (i.e. roads or other significant points) that can be related to features detectable on the image. The features should be spread throughout the map so that the image detail can be rectified to the planimetric map base. If cultural features are not available on the map, it is sometimes possible to use natural features that maintain a high degree of stability. Many stream beds are found to hold their positions over the period that USGS topographic maps are updated.

In the United States, it has been found that the most suitable base maps are published by the United States Geological Survey. Three series of topographic maps (Figure 5) are published at scales of 1:24,000, 1:62,500 and 1:250,000 (U.S.G.S., 1969). At a cost of $1.25 per sheet, the maps are relatively inexpensive and can be obtained for any area in the United States in at least one of the three different scales. Distribution centers are located throughout the United States, including the Map Distribution Center, U.S.G.S. Denver Federal Center, Bldg. 41, Denver, CO 80225.

If area calculation is not a concern, then base map selection is not critical. In this case, a suitable base map may even include an ordinary road map, or a map included in a standard atlas. However, the latter maps create a copyright problem and cannot be reproduced without permission. Most government maps are not copyrighted, which makes the choice of U.S.G.S. maps perhaps the most acceptable map to use for all cases.

C. MAPPING PHASE

The actual production of the initial work map involves the transfer of the relevant data from the image to the initial work map. If a planimetric map is required, the data transfer process of the mapping phase must be controlled by utilizing an accurately prepared base map such as a U.S.G.S. topographic map. Planimetric control can be obtained manually to the accuracy required for most purposes by overlaying the work map (a sheet of frosted mylar drafting film) on the base control map. The cultural features seen on the base map (e.g. highways, boundary lines) can be drawn on the work map to become the planimetric control lines. Automated systems have been developed that maintain accurate planimetric control by utilizing a procedure called electronic resectioning (Tewinkel, 1966).

The data transfer process involves the procedures of: scale change, image rectification, boundary interpretation, land use interpretation, and a field check of randomly selected parcels for verification of accuracy and correction of uncertain interpretations.

Figure 5: Examples of three scales of U. S. G. S. topographic maps that may be used in establishing the base mapping system (STEP 6). These series of maps are generally available from government sources or local blueprint offices at scales of 1:24,000 (7 1/2 minute quad); 1:62,500 (15 minute quad); and 1:250,000. U.S.G.S. is also starting to produce series of topographic maps to coincide with metric units (i.e. 1:100,000). All mapping systems that convert image data to map form require a base map to control the angular, directional, and distance relationships between all points from the image to the map. The U. S. G. S. topographic series has proved most useful in this respect, because each series does provide stated point location accuracies (1:24,000 scale is accurate to 40 ground feet). Government prepared base maps have no copyright restrictions on their use. Many distortions found in the photographic images can be corrected either manually or mechanically and reduced to a planimetric base by using the U. S. G. S. topographic maps as a working base map.

Step 7: Method of Scale Change, Image Rectification, and Data Transfer

Imagery is seldom available or obtained at the same scale as the base work map. Also, most images contain distortions that must be rectified to the planimetric scale of the base map. While several very expensive automatic systems have been developed to perform the data transfer process, most small land use mapping agencies perform the function manually. The data transfer process in land use mapping is the most critical function. The entire statistical analysis of land use data depends upon the accuracy of the interpretation of the imagery and the precise location of parcel boundaries from the image to the work map. Various devices and techniques have been, and are being, developed to assist the transfer of land use data from imagery to maps.

a. The Manual Method

The method of data transfer that has been employed for centuries applies equally to image data transfer and involves the overlay of the work sheet on the base control map and visual transfer of the data (Figure 6). The image is studied for certain identifiable cultural features such as roads and highways. The same roads and highways are identified on the base map and lines are drawn where land use boundaries are desired. Boundaries along fence lines or other differentiating land use boundaries which do not appear as cultural features on the base map are drawn by interpolating the distance between detectable cultural features. The manual process accounts for the necessary scale changes and rectifies the distortions present in most images.

b. The Projection Method

Another common method of transferring data from the image to a work map has been to project the image onto the work map. Some advanced projection methods have been developed such as the Bausch and Lomb Zoom Transfer Scope (Figure 7) which uses the camera-lucida technique of projecting the image and the base map simultaneously onto the same eyepiece by use of mirrors. Several other types of image enlarging projection systems are commercially available. Figure 8 shows a reflecting/projecting, enlarger/reducer in which the image is enlarged onto the work map. Perhaps the simplest method is to use an ordinary projector either through a glass screen or against a matte surface on the wall. Any of the projection systems require that the work map overlay the control base map -- or if not overlayed, that significant control features are copied onto the work map to provide planimetric control. If the projection is through a glass onto the work map (i.e. rear projection), it becomes impossible to place an opaque base control map between the work map and projector. In this event, it becomes essential that control features are sketched on the work map from the base control map before the projection process begins.

c. The Photo Reduction/Enlargement Method

The advent of inexpensive matte surface photo film bases has made the technique of photo reduction/enlargement a more accepted, accurate, and cost effective method of image-to-map data transfer. Either the base map

Figure 6: Manually transferring image data to the base work map (STEP 7a). One of the least expensive and most often used methods of transferring the data from an image to the base map is to inspect the photo, locate points on the photo and locate the corresponding points on the map and draw in boundaries between these points to outline the particular land use parcel on the work map. This method manually corrects or rectifies the distortions on the image created by the camera or other device used to produce the image. Likewise, any changes in scale from the image to the map can be made at this time. Visually changing scales is facilitated by using proportional dividers, 10 point proportional dividers are the most effective in this process.

Figure 7: Illustration of the camera lucinda principal of optically projecting an image onto a base map (STEP 7b). The zoom transfer scope being used in the figure will either reflect or project the image onto the base map. The operator, through a series of mirrors, views the image being superimposed upon the base map. The zoom feature of the scope permits scale changes to be made as the boundaries are being traced onto the map. Also it is possible to rectify some of the images' distortions during this optical-mechanical assisted data transfer process.

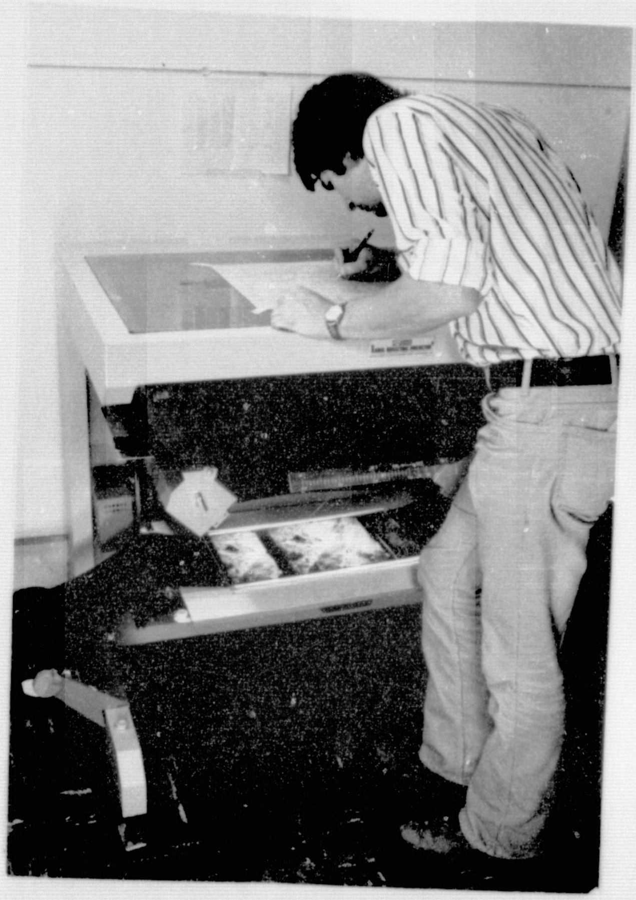


Figure 8: Another illustration of STEP 7b shows another type of mechanical-optical equipment in which the image is reflected or projected onto the base map from the reversde side. This system requires a translucent copy of the base map to be prepared. The object of this data transfer system is to perform the scale change from the image scale to the base map scale. The particular device shown can enlarge the image four times (4X) or reduce the image to one-quarter size (1/4X). Because of the requirement of a translucent base map, this process usually is performed by tracing control features (roads, boundary lines, etc.) from the base map (e.g. USGS topographic sheet) onto a sheet of mylar with a matte surface on one side.

is photographically reduced to the image scale or the image is photographically enlarged to the base map scale (Figure 9). The process provides a black and white transparent film that can be overlayed by either image-on-base map or base map-on-image.

Using the base map for control, the next step is to establish boundaries for each land use type, interpret the land use classification, and produce a planimetric work map.

The boundaries can be quickly established by overlaying the reproduced map transparency on the image (Figure 8) (or the scaled film image over the base map), and drawing appropriate lines between the various land use types.

Interpretation can proceed at the same time that boundaries are being drawn. However, some interpreters find it convenient to do the interpreting separately using a magnifier to get a better "look" at the image data.

Planimetric control is provided by the cultural features on the base map which can be utilized as boundaries where indicated. The natural camera distortion encountered in most images can be rectified by slight adjustment of the overlay. When boundary lines fall between two cultural features of the base maps (e.g. roads), then a slight adjustment may be necessary to interpolate the correct distance between the roads that bound the area. A set of variable calipers with 10 divisions is a useful tool in estimating distances between points.

Certain regions of the world, such as the Western United States, have accurate survey control where land is divided into square mile sections. Quite often property lines fall on even divisions of these sections (e.g. 1/8, 1/4, or 1/2 mile divisions). Using common sense, it becomes a simple procedure to locate accurate boundary lines.

Step 8: <u>Conduct a Field Survey to Check Interpretation Accuracies</u>.

Upon completion of the initial work map, it will be found that some parcels cannot be identified with certainty from the imagery. Also, it is desirable to know what accuracy was obtained in the interpretation process. A field survey becomes necessary at this point to answer these questions. Obviously, a 100% field survey would negate the purpose of performing the land use mapping by photo interpretation. A common sampling technique useful in this instance is "random sampling". A grid matrix of 100 x 100 cells is overlayed on the work map. A four-digit table of random numbers is used to produce 100 cell numbers on the matrix. The parcels falling under these 100 random cells become the targets for the field survey. The accuracy of the map is then established by verifying on the field survey the correctness of the laboratory interpretation. Likewise, the field survey will provide the classification identity of those parcels that could not be interpreted in the laboratory.

Figure 9: Relatively inexpensive photo-enlargements can be made of the images as a positive transparency on photographic film with a matte surface. (STEP 7c). The enlargement is made to the scale of the base map, or the base map can be reduced to the image size by the same photo process. The purpose of the photographic enlargement procedure is to permit the image to be used as an overlay on or under the base map. Having changed the scale photographically, it becomes a simple procedure to draw in the boundary lines of each land use parcel on the base map by visual inspection of the image. Rectification of the distortions of the original image are still present in the enlargement, but they can be rectified by moving the image features to correspond to the respective control features on the base map.

D. DATA COMPILATION AND PRESENTATION PHASE

The data on the work map is now verified and the working map is planimetrically correct. The work map consists of a set of connected boundaries (polygons) and associated land use attributes. We are now faced with the decision as to what method should be used to prepare a final map that meets the previously determined quality.

Step 9: Select Method of Final Reproduction

The work or 'draft' map may be all that is required by the user and the map is completed. However, most users desire a map where each land use type on the map is colored or shaded the same legend. If only one final copy that is not intended to be changed or updated is desired, then the final map probably should be accomplished manually. However, if area calculations are required for the various types of land use and/or the map data is to be periodically updated, or the land use data is to be combined with other information for a composite type presentation, it may be worth the time and effort to encode the data into computer compatible format and reproduce future maps and changes automatically.

Step 10: Prepare a Clean Copy of the Land Use Map

Whether the final map is produced manually or by machine procedure, a "clean" map will be required for further processing. In manual production, the "clean" copy often is obtained by inking in the boundary lines and cleaning up the other areas with various drafting techniques. In machine processing there are several considerations. The degree of cleanliness depends upon the method of data conversion.

If the work map was produced on mylar film (e.g. photo enlargement of the image or topographic map) with all the shades of gray of the original image, or all the topographic features of the map (e.g. contour lines), then the line work must be extracted from the background. In many cases, the only reasonable solution is to redraw the desired boundary lines on a clean mylar overlay. Using a light table, this procedure can be accomplished rapidly.

In addition to removing unwanted detail on the work map, it is also necessary to provide additional data conversion information for machine processing. One method of data conversion is for an operator to digitize each line segment of the work map. If each polygon is digitized independently, the result is double digitizing. That is, the line segments are digitized twice; once for each adjacent polygon. This presents no problem at the intersection of lines. However, where a line segment bends, the operator must know where to locate a vertex point for that bend so that he digitizes the same location for both adjacent polygons. Hence, the preparation of a "clean" map copy for machine conversion may also include placing tic marks on any line segment that changes direction other than at the intersection of two or more lines. Figure 10 is an example of a land use map prepared for digitizing.

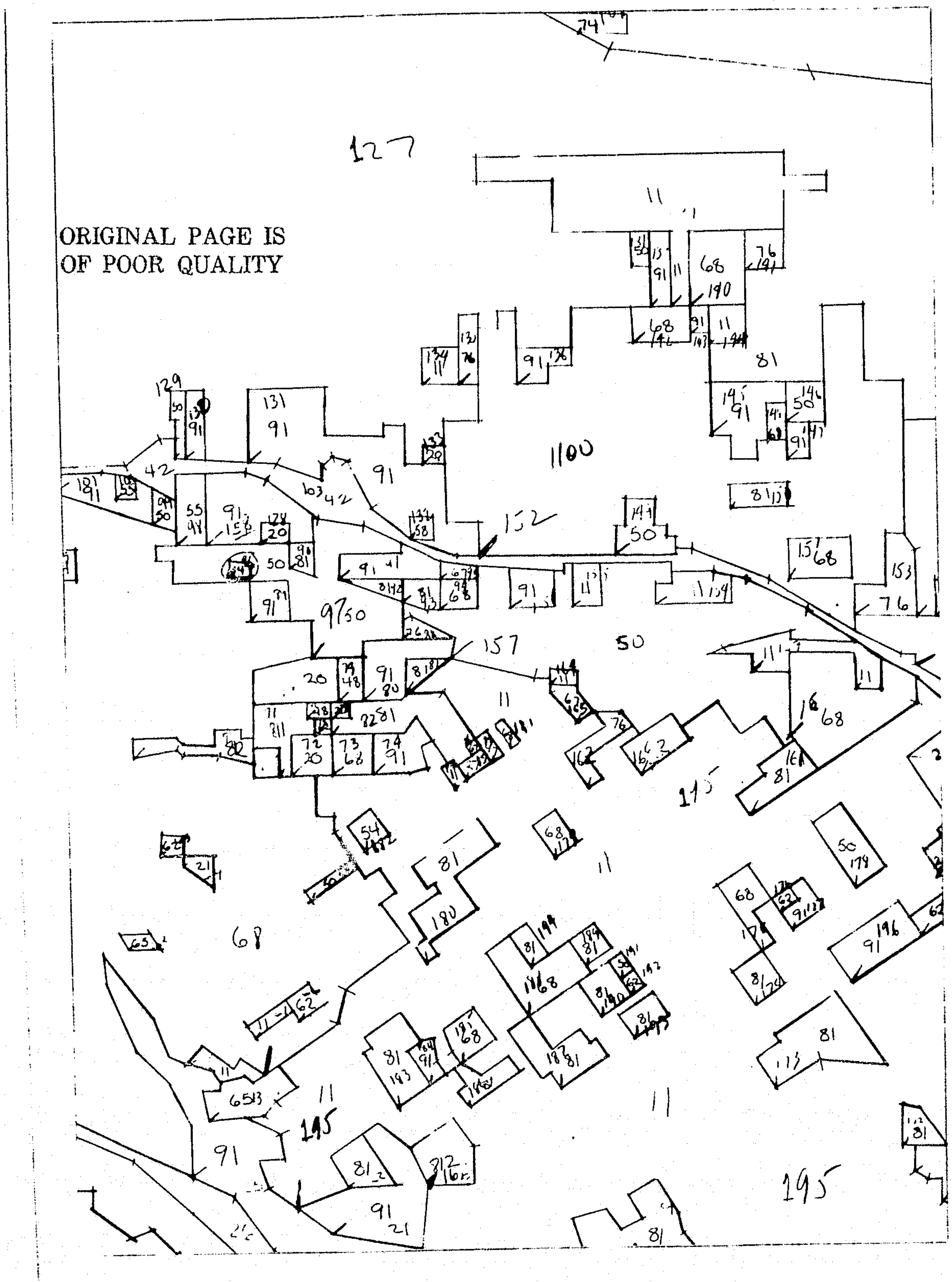


Figure 10: Example of a "clean" land use work map prepare for conversion of data into machine (digital) format (STEP 10). All lines extraneous to the final map are removed. Each parcel is numbered and its land use code is entered. Beginning point of each polygon (parcel) is given a tic mark (lower left hand point). All change of directions on line segments that are not 90° intersections are given a tic mark for convenience of relocating the point when double digitizing the boundary lines.

Step 11: Convert "Clean" Work Map to Machine Format

The remainder of discussion in this phase considers the problems of machine production of land use maps because manually produced maps would be completed at the end of step 10.

a. Machine Digitizing

The conversion of a map to machine format can be accomplished in several ways, including manual conversion utilizing a coordinate overlay, or through the use of any one of the many machine scanners or line followers which have been developed. The discussion will be limited to manual conversion procedures using an x-y coordinate table.

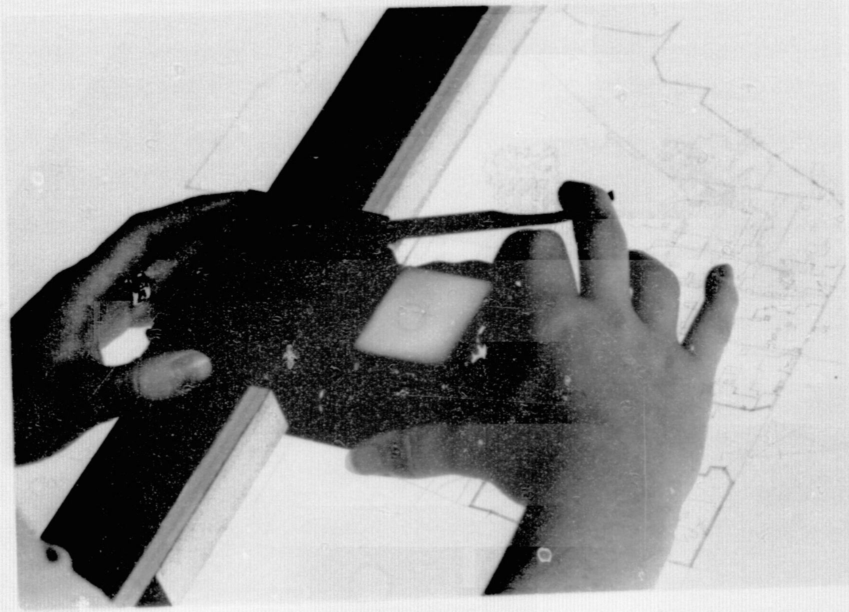
A commonly used device for map data conversion is a coordinatograph (Figure 11). This is a table and associated electronics that will measure the X and Y coordinates of a point from a pre-set origin to accuracies of from one-hundredth (0.01) of an inch to ten-thousandths (0.0001) of an inch. The finer the resolution of measurement, the costlier the machine. Most land use or thematic map data conversion can be accomplished with a resolution of one-hundredth (0.01) of an inch. By means of mechanical and optical encoders, the analog map data are transferred to electronic equipment that converts the analog measuring signal to a digital machine readable form. The data are now converted from manual processing and all further processing is accomplished within computer systems. Details of the computer system may be found in section 5.3, Overview of the Spatial Information Processing System (SIPS).

b. Procedural Error Editing

Both time and money can be saved if the raw converted map data is subjected to a preliminary edit procedure. The edit is designed to detect procedural errors that are caused by the human operator. Most of the human errors are excusable because digitizing is a tedious task and requires close concentration with considerable eye-strain occurring during the process. The visual editing of converted data is laborious, time consuming and inaccurate. A computer editing program performing the same operations takes about 30 seconds time (even for a detailed map) and detects all procedural errors. For example, if the operator failed to close a polygon (return to the original starting point), the program will detect that condition, which would otherwise lead to an ambiguous situation. The operator must then correct the errors (Figure 12). Manual edit of the same data may take one to two hours and not necessarily detect all the errors.

c. Geometric Editing

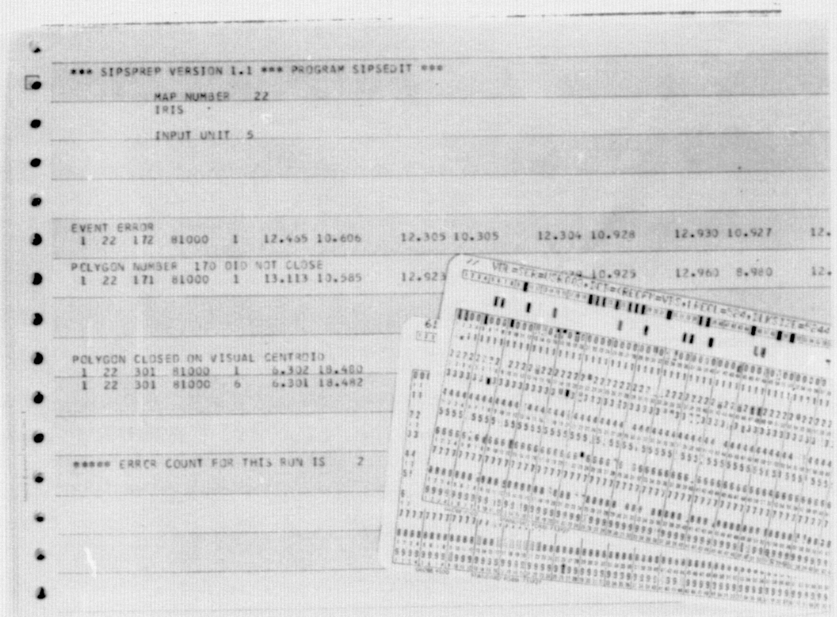
Once the raw data has been edited and corrected, a test map must be plotted (Figure 13). The test map is then edited for geometric errors in digitizing that occur either through machine failure or operator error. If the operator fails to locate the same point within a set selected tolerance (0.01" to 0.03"), a double line may be created bordering adjacent polygons. This error is apparent on the test map as a double line. Overlaying the test map on the "clean" work map will detect the error. The double line



a

b

Figure 11: Conversion of the "clean" work map into machine (digital) format (STEP 11a) is performed on a digitizer or coordinatograph table. The table has a movable cursor (either floating or fixed to a moveable arm) that is geared to an optical encoder (bowls at top of arm and upper right hand corner of table) which activates an electronic encoding system that converts the X-Y coordinate points of the table to digital codes. The X-Y coordinates are measured to accuracies of 0.01 or 0.001 inches from a pre-selected origin point on the table. Most land use mapping can be performed to an acceptable accuracy by using a table that will encode points to 0.01 inch.



a

b

Figure 12: Procedural errors that occur during the digitizing process must be corrected before a final map can be plotted (STEP 11b). An edit program has been written for the Spatial Information Processing System (SIPS) that performs the machine compilation for reproducing the land use maps. The edit program is written to detect all the possible errors that can occur during the digitizing process (e.g. Two polygons given the same number; vertice sequence numbers not correct (event number error); Polygon (parcel) was not closed). Figure a shows a sample listing. Figure b shows the correction of machine cards utilizing the edit listing and the original work map.

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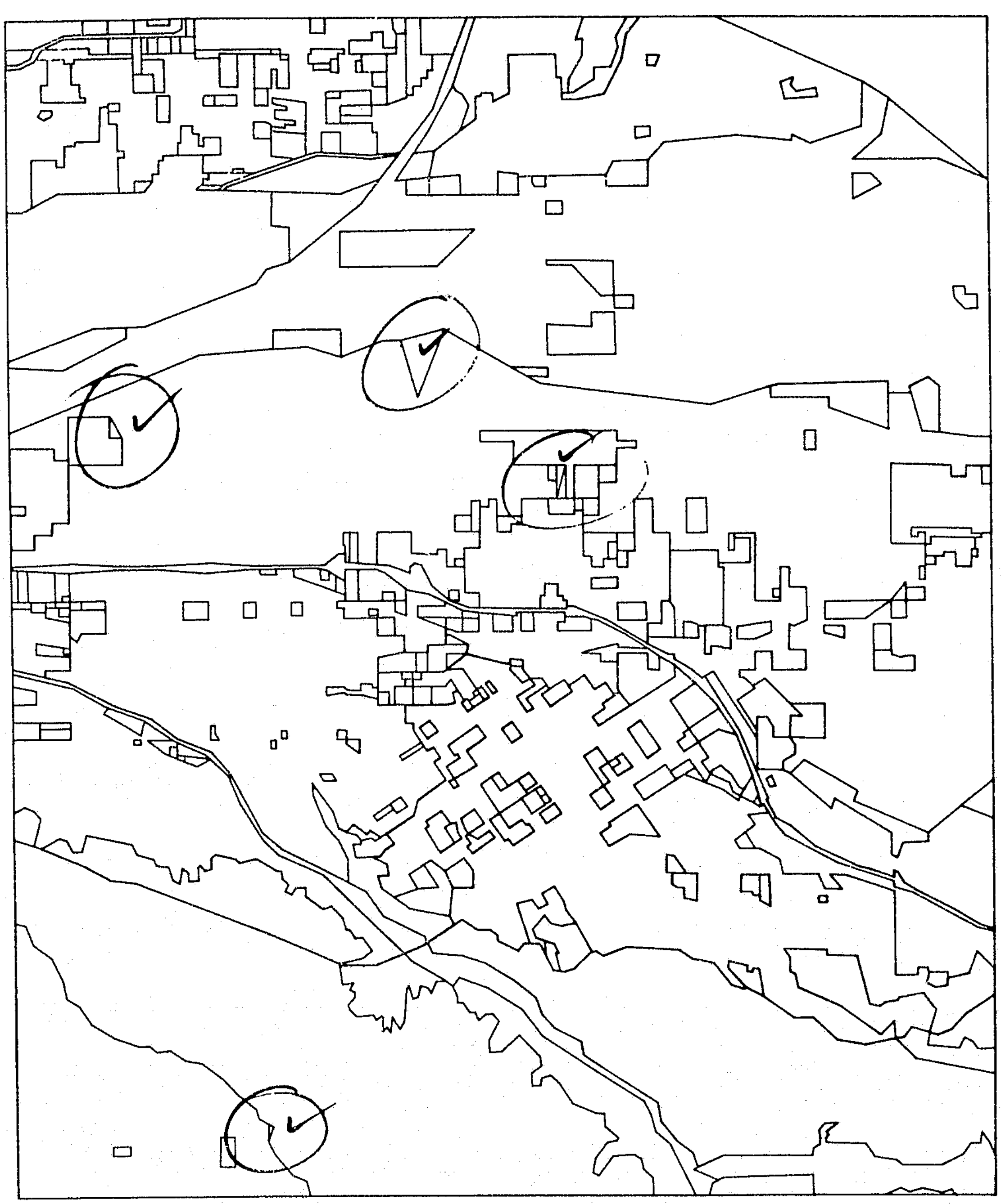

Figure 13: Geometric errors occurring during the digitizing process must be corrected by producing a test map (STEP 11c). The digitizing process is performed for each polygon separately. This system results in double digitizing each line (clockwise for one polygon and counterclockwise for the adjacent polygon). If the operator skips a point around the boundary of a polygon, it will create a "spike" as shown in the example. If the tic marks had not been placed on the "clean" work map (Figure 10), the example would show many "slivers" where the operator was not able to locate the precise point that was digitized for the adjacent polygon.

may also create a calculation error in determining the area of a polygon. Occasionally, the conversion equipment will malfunction and not record the correct X or Y coordinate, or the computer will be unable to read a coordinate and substitute a zero value. A "spike" will be created which causes the plotter to draw a line from its last position to some distant point on the map. When all the geometric errors are corrected, then final map production can begin.

Step 12: <u>Produce Statistical Tabulation of Land Use Data</u>

One purpose for machine production is to be able to accurately compute the land use areas. Once the final edit and corrections have been made, the area data can be generated with assurance of accuracy (i.e. less than 1% error in computed area). Digital computers permit rapid computation of areas for individual polygons (Figure 14a). In addition, a more useful tabulation is a compilation of total area for each land use classification present on the map (Figure 14b).

Step 13: <u>Produce Final Land Use Maps</u>

The final step in land use or thematic map production is to draw or plot a shaded or colored map - commonly called a choroplethic map. At this point, the computer cannot determine the shades and/or the colors to be used for the various land use types. The computer must be instructed as to which shade and/or color is to be placed in each polygon. Reference should be made to any one of several standard cartography textbooks for the theory of shade and coloring techniques. Generally, the feature to be emphasized will have the densest shade or be selected from the red end of the color spectrum.

Some computer programs will produce part or all of the map legend; otherwise legends must be added manually. Titles and subtitles are an essential part of a map. Each map should have a scale. If the map is to be photographically changed in scale, then a graphic bar is the only scale that can be placed on the map. Other types of scales (e.g. representative fractions) lose their meaning when the map is photographically reduced or enlarged.

There can be several overlay features added to the final map, either manually or by computer. If a user needs a road network for a reference system, it can be drawn in by machine or manually. Other reference areas such as place names can be similarly added.

Figure 15 shows a four pen flatbed plotter that permits both the outline of the land use map to be drawn and each parcel to be shaded with up to four colors. Four colors will permit 45 different landuse categories to be shaded, whereas only 12 landuse areas can be shaded with one pen. Figure 16 is an example of a one pen shaded landuse map showing both urban and rural landuse.

AREA CALCULATIONS

SCALE FACTOR IS 9.58

POLYGON	TYPE	ACRES	HECTARES
1	1100.	5.33	2.16
2	1100.	14.70	5.95
3	9100.	1379.04	558.08
4	9100.	3350.67	1355.97
5	8100.	140.43	56.83
6	8160.	359.57	145.51
7	9300.	197.44	79.90
8	9100.	65.88	26.66
9	9100.	10.60	4.29
10	8100.	336.93	136.35
11	7400.	72.67	29.41
12	1100.	63.36	25.64
13	9100.	2074.59	839.56
14	7400.	193.86	78.45
15	6800.	9.43	3.82
16	9100.	320.72	129.79
17	8100.	6.29	2.55
18	6200.	55.64	22.52
19	8100.	47.95	19.41
20	9100.	9.16	3.71
21	9100.	52.24	21.14
22	8100.	13.51	5.47
23	6500.	19.84	8.03
24	1100.	7.68	3.11
25	9100.	127.78	51.71
26	9300.	121.70	49.25
27	9100.	441.73	178.76
28	9100.	26.67	10.79
29	9100.	15.61	6.32

AREAS BY TYPE

TYPE	ACRES	HECTARES
1100.	6461.34	2614.81
1400.	170.31	68.92
2000.	103.30	41.81
2100.	4.23	1.71
2400.	77.09	31.20
2700.	3.34	1.35
3400.	9.97	4.03
3900.	6.52	2.64
4200.	232.60	94.13
4300.	101.04	40.89
4700.	2.62	1.06
4800.	223.15	90.30
5000.	568.12	229.91
5400.	5.88	2.38
5500.	19.16	7.76
5800.	13.25	5.36
6200.	95.64	38.70
6500.	22.94	9.28
6700.	41.02	16.60
6750.	1207.33	488.59
6800.	555.20	224.68
6900.	1.57	0.64
7200.	27.27	11.03
7400.	410.73	166.22
7600.	68.33	27.65
7900.	1.39	0.56
8100.	2555.65	1034.24
8110.	3352.25	1356.61
8120.	6400.10	2590.03
8160.	359.57	145.51
8200.	27.84	11.26
8500.	143.39	58.03

Figure 14: One of the products of SIPS is a statistical tabulation (STEP 12) of the data compiled by the computer process. The example shows the area calculation for each polygon (parcel) and a summation of the total area for each land use type found on the map.

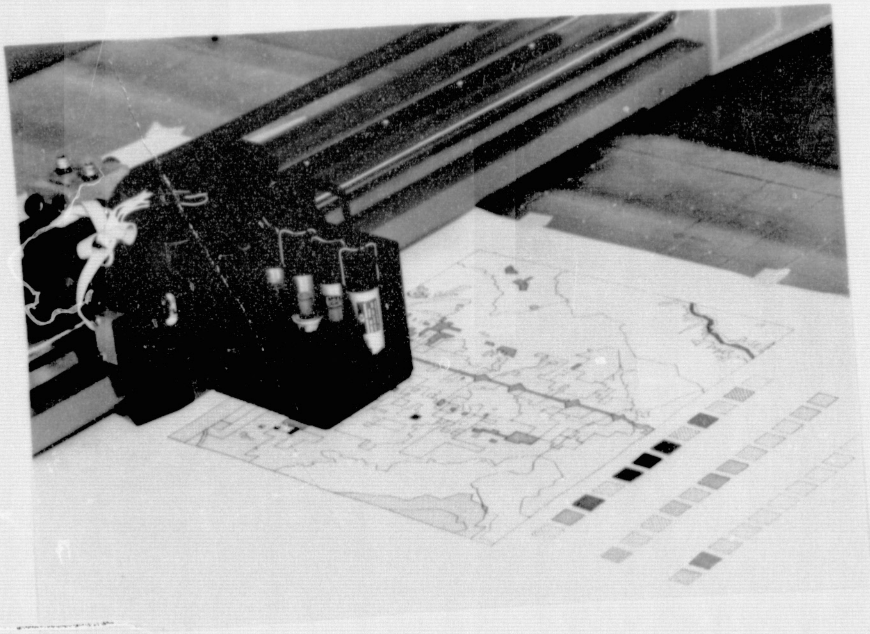

Figure 15: The final STEP 13 is the production of the completed land use map. The illustration shows a flat bed plotter with a 4 pen head that enables four different color or four different pen widths to be used alternately. A flat bed plotter is used when precision plotting is desired for the final map. The particular plotter shown permits the final map to be overlayed on the original base map and all lines will be coincident. For maps that do not require such precise tolerances, there are many less expensive drum type plotters available.

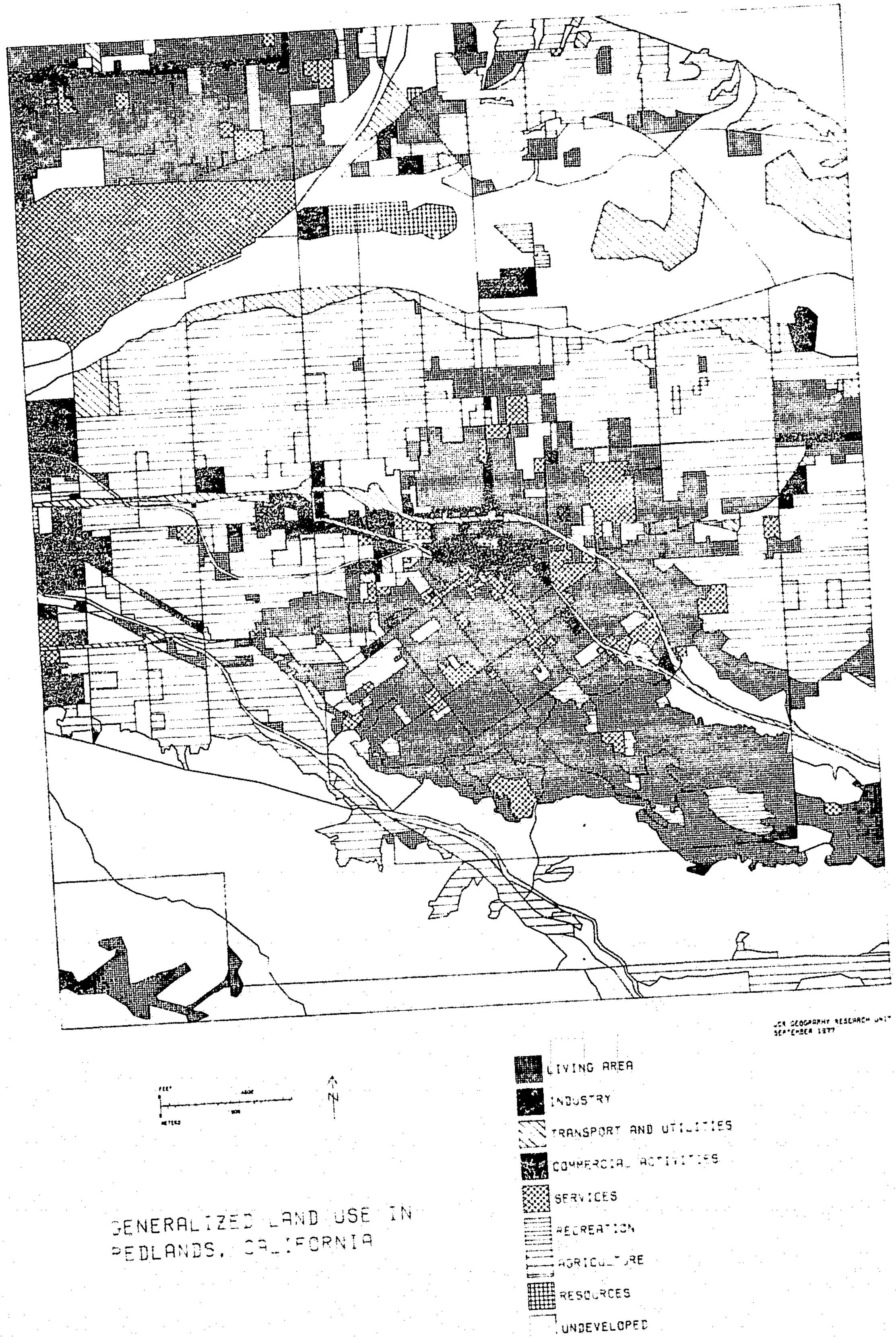

Figure 16: The final product (STEP 13) is illustrated in the above map produced from the Spatial Information Processing System (SIPS) from a one-pen plot. Nine black and white shades are possible from one pen showing the first level of the land use classification code.

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Appendix 5-II

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APPLIED GEOGRAPHY

REMOTE SENSING OF WATER DEMAND INFORMATION

JOHN R. JENSEN, JOHN E. ESTES, LEONARD W. BOWDEN, and LARRY R. TINNEY

WATER resource problems are widespread, and resource management models capable of structuring and synthesizing the mass of data for large areas into a format for efficient analysis are in an early stage of research and development. Water supply and demand models of varying levels of application are currently available; however, the models are usually localized in areal extent and rely mainly on historical data. Future water consumption is generally projected from historical land use or land cover information, census tract data, water hookup and meter records, or other surrogate information.[1] However, if we are to maximize water supply to meet demands, we must have near real-time statistics on water demand on a regional, state, national, and even international basis.

Earth resource satellite systems such as Landsat, capable of providing this input data to drive models, have only been operational since 1972.[2] The basic need for such data led investigators conducting General Electric's "Total Earth Resources Systems for the Shuttle Era" (TERSSE) study to identify two priority missions as: to survey and inventory the volume and distribution of surface water and groundwater in order to assess available supplies for urban and agricultural consumption; and to survey and monitor cropland in the United States in order to calculate estimates of short-term and long-term demand for irrigation water.[3]

For several years prior to the TERSSE evaluation, the National Aeronautics and Space Administration (NASA) funded the University of California to develop remote sensing procedures to be used in analyzing and predicting water supply and demand.[4] Studies in central and southern California have focused on the identification of critical water demand parameters that can be inventoried by multidate, high-altitude aircraft photography and Landsat image-processing methodologies. In conjunction with the California State Department of Water Resources (DWR) and various local districts and agencies, it was determined that the most reliable surrogate parameters indicative of water demand for a given area are land use and population density. Detection of land use change and environmental modification are possible

[1] Surrogates often used to produce data on water consumption are: type of crops per unit area, coupled with average irrigation rate for that crop; or class and area of residential land use, coupled with statistics for average water consumption for such land use. Future demand models are based on per capita or per area consumption and projected change in population and/or land use.

[2] Landsat-1, formerly called the Earth Resources Technology Satellite (ERTS), was launched on July 20, 1972. A second Landsat was launched in 1975. These first two Landsat series satellites carry the same prime remote sensor complement: three return beam vidicon (TV-type) cameras operating in three separate wavelength bands, .475μm–.575μm (designated channel 1), .580μm–.680μm (designated channel 2), and .690μm–.830μm (designated channel 3); and a four-channel multispectral scanner system operating at .500μm–.600μm (designated channel 4), .600μm–.700μm (designated channel 5), .700μm–.800μm (designated channel 6), and .800μm–1.100μm (designated channel 7).

[3] "Definition of the Total Earth Resources System for the Shuttle Era" (10 vols.; General Electric Space Division, Philadelphia, 1974), Vol. 3, pp. 3-11.

[4] "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques" (edited by R. N. Colwell; Ann. Rept., NASA Grant NGL 05-003-404, 1976). Under this grant basic research on water demand is being conducted at the Riverside and Santa Barbara campuses of the University of California. Water supply research is conducted at the Berkeley and Davis campuses.

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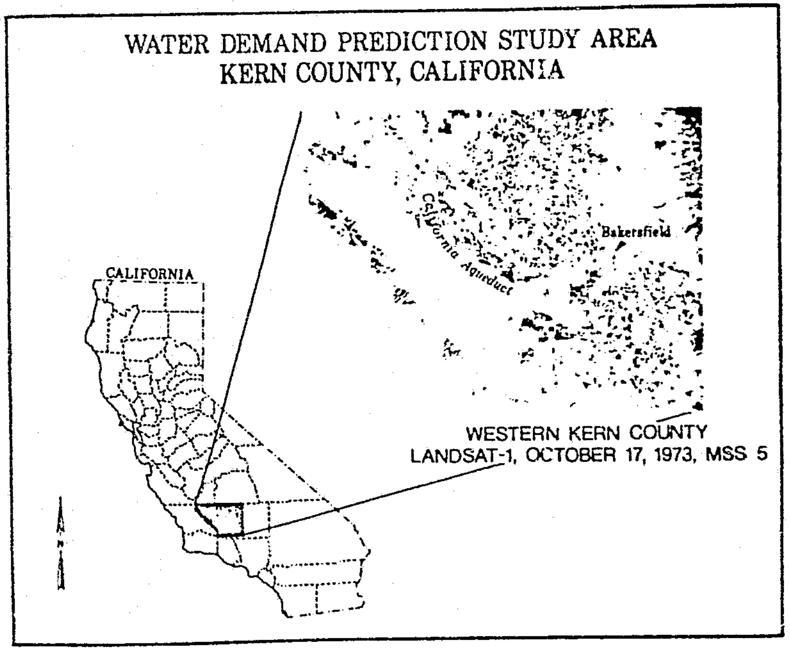

Fig. 1—The agricultural water demand prediction study area in Kern County, California. Situated in the semiarid southern part of the San Joaquin Valley, it is the second most productive agricultural county in the United States.

by remote sensing techniques and can provide data for modeling both short-term and long-term water demand.[5] The degree to which the procedures developed are general or site-specific is being evaluated by University of California researchers, and the role of future satellite and sensor technology to be used in water demand models is being assessed.

The results of research in Kern County and the Upper Santa Ana River Basin demonstrate the capability of remote sensing to provide data for both urban and agricultural water demand models. In each study, a methodology is demonstrated to highlight the basic premise that remote sensing has an impact on the environmental modeling process by providing spatial, accurate data through time at scales compatible with model information requirements. The Kern County study documents the application of remote sensing techniques and methodologies to agricultural water demand modeling; the Santa Ana River Basin study describes the use of remote sensing data as input into an empirical model that utilizes net land use information as the driving parameter for predicting both urban and rural water consumption.

[5] The use of remote sensing of the environment in water resource research is described in William Meyer and Robin I. Welch: Water Resources Assessment, *in* Manual of Remote Sensing (2 vols.; Amer. Soc. of Photogrammetry, Falls Church, Va., 1975), Vol. 2, pp. 1479–1551; Victor I. Myers: Crops and Soils, in *ibid.*, Vol. 2, pp. 1715–1813; Robert W. Peplies and Harold F. Keuper: Regional Analysis, in *ibid.*, Vol. 2, pp. 1947–1998; and H. Homer Aschmann, Leonard W. Bowden, Thomas R. Lyons, and Ralph S. Solecki: People: Past and Present, in *ibid.*, Vol. 2, pp. 1999–2060. Image data input and information systems are described in Dieter Steiner and Anthony E. Salerno: Remote Sensor Data Systems, Processing, and Management, in *ibid.*, Vol. 1, pp. 611–803.

TABLE I—KERN COUNTY WATER AGENCY HYDROLOGIC MODEL INPUTS AMENABLE TO REMOTE SENSING

MODEL REQUIREMENT	DEFINITION	CONVENTIONAL SOURCE	REMOTE SENSING PARAMETERS: Analysis techniques and spectral regions
Agricultural usage			
Gross irrigated acres	Irrigated acreage total	Periodic air surveys; fieldwork	*Irrigated croplands:* multiband, multitemporal, multistage discrimination; photographic region
Unit agricultural consumptive use	Acre-feet water requirement by individual crops	Dept. of Water Resources crop experiments	*Crop identification:* multiband, multitemporal, multistage discrimination; photographic region
Surface and groundwater movement			
Volume of moisture deficient soil	Volume of unsaturated soil	Fieldwork (soil surveys)	*Soil moisture:* complex modeling of responses from thermal infrared and microwave regions
Percent to perched water table	Percent of node overlying perched water table × nodal deep percolation	Fieldwork	*Perched water tables:* multispertral, multitemporal analysis of photographic, thermal infrared, and microwave data

KERN COUNTY AGRICULTURAL WATER DEMAND

Kern County, California (Fig. 1), is the second most productive agricultural county in the United States, with an estimated value of direct farm marketing in 1976 of more than $750,000,000. Production depends primarily on the irrigation of about a million acres.[6] Kern County consumed more than 884,000 acre-feet of California Aqueduct water in 1976 at a mean cost of $20 per acre-foot for the twenty-one water districts in the county. Groundwater in excess of two million acre-feet, or about three times the amount being imported by the state project, is extracted annually. Kern County's dependence on groundwater, at rates exceeding a safe yield, has resulted in a continuous decline of the water table in most of the county.[7]

Analysis of projected California Water Project deliveries through 1990 indicates that irrigation water applied to crops and water used to replenish groundwater supplies will account for approximately 85 percent and 10 percent of the Kern County water demand, respectively. The remaining 5 percent is required to meet urban-industrial and recreation demands. The need for 1990 contracted supplies of imported state water will be realized as early as 1980, and if Kern County expands irrigated agriculture, the overdraft of groundwater will continue.

In 1970 the Kern County Water Agency (KCWA) developed a digital computer model of the regional groundwater basin.[8] The model was initially calibrated using historical data and relied heavily on agricultural land use data derived from terrestrial surveys. The purpose of the model is total simulation of water transmission and storage in the Kern County water basin.

After analyzing all model variables, it was concluded that remote sensors could provide data for several critical model parameters (Table I). The KCWA model incorporates both geological and agricultural land use information. The most dynamic element of the model is the amount of irrigation water applied to agricultural lands. Water may either be pumped from local groundwater basins, lowering groundwater levels, or imported from other regions. Neither the amount of groundwater pumped nor the amount of irrigation water applied is accurately known, yet accurate estimates of each are required by the KCWA model. The amount of water applied is best estimated from a knowledge of the total number of irrigated acres and the agricultural water requirements of this acreage under a given set of environmental conditions. The bulk of our remote sensing research in agricultural water demand modeling has been directed at inventorying the irrigated acreage component of this water demand equation. The approach can take the form of either general cropland/noncropland inventories, in which fields are designated as simply being cultivated or noncultivated, or "crop-specific" inventories, in which the type of crop is identified.[9]

[6] *1976 Annual Crop Report for the County of Kern*, U.S. Dept. of Agriculture, Bakersfield, Calif., 1976, pp. 1–8.

[7] *Kern County Water Agency, Ann. Rept., 1972 and 1973*, Bakersfield, Calif., 1974, p. 8.

[8] The Kern County Water Agency's groundwater model was developed by the TEMPO Center for Advanced Studies in Santa Barbara, California, a subsidiary of General Electric.

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TABLE II—COST-EFFECTIVENESS OF TERRESTRIAL VERSUS REMOTE SENSING TECHNIQUES FOR A CUMULATIVE MULTIDATE CROPLAND INVENTORY OF THE LOST HILLS, SEMITROPIC, AND WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICTS, KERN COUNTY, CALIFORNIA

CROPLAND MAPPING		COST OF INVENTORY (in dollars)		HOURS REQUIRED TO INVENTORY DISTRICTS
Agency	Technique	Districts	Per 10,000 acres	
Lost Hills, Semitropic, and Wheeler Ridge-Maricopa Water Storage Districts	Terrestrial	3,000	66.00	240
Department of Water Resources	Low-altitude color photography and terrestrial	2,850	63.00	230
Geography Remote Sensing Unit	High-altitude 1:125,000 color infrared photography	136[a]	3.00	8
Geography Remote Sensing Unit	Landsat 1:1,000,000; Band 5	90[a]	2.00	15

[a] This includes the cost of imagery reproduction by NASA but does not include the cost of aircraft or spacecraft mobilization.

REMOTE SENSING CROPLAND ACREAGE AS WATER DEMAND INFORMATION

To test the effectiveness of remote sensing to provide cropland information as a model input, photointerpreted data obtained from color infrared high-altitude photography (1:125,000) and from Landsat imagery (1:1,000,000; Band 5) were compared with data derived from conventional ground survey techniques.[10] KCWA personnel conducted the field inventories by direct examination.[11] Their data, recognized as having its own variance, served as a control against which the remote sensing methodologies were tested for accuracy.

The total estimated cost for conducting a 456,000-acre (184,534-hectare) terrestrial inventory by water district personnel was approximately $3,000, and it required six weeks to complete (Table II). At this rate, the cost for inventorying each 10,000 acres (4,047 hectares) is approximately $66. The Department of Water Resources estimated that a cropland survey of Kern County could be undertaken for approximately $5,000.[12] The cost would therefore be approxi-

[9] John E. Estes, John R. Jensen, and Larry R. Tinney: Water Demand, *in* An Integrated Study [see footnote 5 above], pp. 3–10.

[10] John R. Jensen, Larry R. Tinney, and John E. Estes: An Analysis of the Accuracy and Cost-Effectiveness of a Cropland Inventory Utilizing Remote Sensing Techniques, *in* Tenth International Symposium on Remote Sensing of Environment (edited by Jerald J. Cook; Environmental Research Inst. of Michigan, Ann Arbor, 1975), pp. 1149–1158.

[11] This expensive ground truth information is obtained by terrestrial "windshield" surveys each year. Typically the water agencies assume a ± 5 percent error in crop acreage estimates made by conventional field survey techniques.

[12] Written correspondence from Frederick E. Stumpf, Chief, Water Utilization Section, San Joaquin District, California State Dept. of Water Resources, Sept. 17, 1975.

TABLE III—MEAN RELATIVE AND ABSOLUTE CROPLAND ACCURACIES FOR A CUMULATIVE MULTIDATE INVENTORY OF THE LOST HILLS, SEMITROPIC, AND WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICTS, KERN COUNTY, CALIFORNIA

TYPE OF LAND	GROUND INVENTORY (*in acres*)	INTERPRETED ACREAGE: Cropland	INTERPRETED ACREAGE: Noncropland	MEAN ABSOLUTE ACCURACY	MEAN RELATIVE ACCURACY
High Altitude (1:125,000) Inventory					
Cropland	288,694	281,771	6,924	97.6	99.7
Noncropland	.67,289	6,096	161,191	96.3	99.5
TOTAL	455,983	287,867	168,115	97.1	99.7*
Landsat (1:1,000,000; Band 5) Inventory					
Cropland	288,694	283,624	5,070	98.2	99.8
Noncropland	167,289	4,376	162,913	97.4	99.6
TOTAL	455,983	288,000	167,983	98.0	99.7*

* Area weighted.

TABLE IV—LANDSAT MULTIDATE CROP CLASSIFICATION ACCURACY, NODE 199 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, KERN COUNTY, CALIFORNIA, 1973

GROUND TRUTH	NUMBER OF FIELDS	CLASSIFICATION ACCURACY (*percentage*)	LANDSAT MAXIMUM LIKELIHOOD CROP CLASSIFICATION* (*in acres*): Barley	Cotton	Melons	Safflower	Sugar beets	Total
Barley	5	80	322		82			404
Cotton	37	97	80	2,219				2,299
Melons	6	72	20		258		80	358
Safflower	4	100				152		[illegible]
Sugar beets	5	67			85		176	261
TOTAL	57	90	422	2,219	425	152	256	3,474

* Channels 7/18/73 MSS-5 and 10/17/73 MSS-7.

mately $2,850 to inventory the 456,000 acres in the three water districts under investigation. The DWR cropland inventory cost, utilizing hand-held, oblique, color aerial photography and extensive field survey was estimated to be $63 per 10,000 acres.

The cost of acquiring cropland data by color infrared high-altitude photography is competitive when compared to conventional terrestrial methods (Table II). For each 10,000 acres inventoried, the cost is approximately $3. Eight hours were required to complete the analysis. The $136 cost of acquiring remotely sensed cropland data represents approximately 5 percent of the $3,000 incurred by the water storage district's conventional data collection system. However, the cost of aircraft overflight must also be considered in single-purpose surveys. Inventorying the area via Landsat imagery is even less expensive, approximately $90, or $2 per 10,000 acres, because image acquisition costs are lower.

In terms of mean absolute accuracy (Table III), the Landsat cumulative multidate (band 5) black-and-white analysis yielded slightly superior results versus the high-altitude color infrared inventory. However, analysis of individual interpreter performance confirmed that there was no significant difference between the high-altitude and Landsat remote sensing techniques, both of which are almost as accurate as conventional surveys. Because Landsat imagery is more economical to acquire, it may be preferable. Photo interpreters are now providing the KCWA hydrology model with quarterly Landsat cropland acreage statistics.

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REMOTE SENSING "CROP-SPECIFIC" ACREAGE AS WATER DEMAND INFORMATION

Cropland mapping using remote sensing techniques such as those described above permits a general approximation of water demand. Crop-specific acreage information can be used to yield a much more accurate prediction of agricultural water demand when used in conjunction with crop-specific application rates.[13] Remote sensing techniques that generate such specific crop information for input into the acreage component of the water demand equation, however, require multispectral and multidate imagery because of the complex overlapping of plant growth cycles present in the Kern County agricultural environment. Multispectral analysis is based on the premise that spectral signature differences exist between different classes of objects (in this case agricultural crop types) when recorded in discrete regions of the electromagnetic spectrum. At present, the Landsat multispectral scanner (MSS) configuration is one of the most useful sources of spectral data, for it images objects in four discrete wavelength regions (that is, bands). The spectral bands are adequate for crop identification purposes but not optimized for such a task. Nevertheless, it is the only semioperational system yielding spectral information at a spatial resolution (80 by 60 meters, or approximately 1.14 acres per picture element) sufficient for crop identification purposes.

Accurate crop identification also requires that spectral data be obtained at optimum times throughout the growing season in order to distinguish one crop from another. Such multitemporal analysis commonly involves the use of plant phenology (that is, crop calendar) information. Knowledge about the types of crops present in a region and their respective growth characteristics can be used to select optimum dates of imagery for the classification procedure. Two Landsat satellites, if set in the proper orbital configuration, can cover an area every nine days, providing adequate temporal resolution for imaging certain crops in important developmental stages.[14]

Remote sensing procedures developed for crop identification in Kern County may be subdivided into the following procedural tasks: (1) the spatial registration of multiple date imagery so that corresponding elements of the same ground area appear in the same place on registered images. In this manner, the digital number (dn) gray scale values of any two images at any (x, y) coordinate or resolution cell will represent the sensor output for the same object; (2) extraction of the spectral information for each field; and (3) classification. By using a limited amount of "crop-specific" information obtained from field surveys or other collateral sources, it is possible to "train" a classification algorithm. Once trained, the classification algorithm may be applied to "test" regions. The actual decision rule used for classification is commonly either a maximum likelihood or linear discriminant function.

Previous research on a twenty-one-square-kilometer crop identification test region in the Wheeler Ridge-Maricopa Water District, Kern County, will be used to demonstrate the above procedure. Out of thirty-one bands of Landsat data available for the 1973 crop year, the two most optimum channels were selected and interrogated via the LARSYS maximum likelihood decision rule.[15] The Landsat crop identification performance for barley, cotton, melon, safflower, and sugar-beet fields is compared in Table IV with the water district records. Overall,

[13] Such "crop-specific" average application rates are available on a regional basis from both the University of California Agricultural Extension Service and the U.S. Department of Agriculture. These statistics normally take into account local soil associations, crop species, and environmental parameters such as microclimate.

[14] Claude W. Johnson and Virginia B. Coleman: Semi-Automated Crop Inventory from Sequential ERTS-1 Imagery, *in* Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Vol. I: Technical Presentations (edited by Stanley C. Freden and others; Natl. Aeronautics and Space Admin., Washington, D.C., 1973), pp. 16-26.

[15] All test fields were classified using the LARSYS per field classification algorithm. This algorithm is based on an equally weighted maximum likelihood decision rule. A simple maximum likelihood decision rule is one that treats each picture element (pixel) independently and assigns a pixel having pattern measurements or features d to that category c, whose units are most probable to have given rise to pattern or feature vector d, that is, such that the conditional probability of d given c, $P(d/c)$, is highest. Normal or

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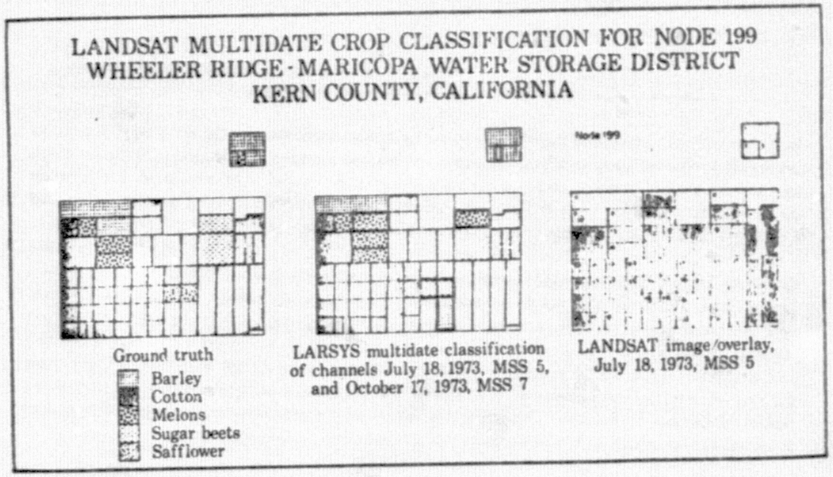

FIG. 2—LARSYS maximum likelihood crop classification of the two most optimum channels (as specified by divergence/separability statistics), compared with the ground truth map. Misclassified fields are outlined. The Landsat image overlay illustrates one channel of information used in the analysis. Crop identification classification accuracies associated with this inventory are given in Table IV, and water demand prediction in Table V. LARSYS is a maximum likelihood algorithm developed at the Laboratory for Application of Remote Sensing, Purdue University, West Lafayette, Indiana.

Landsat classification was 90 percent accurate, with three of the five crops being classified accurately at least 80 percent of the time. Landsat misclassified fields in Table IV can be identified in Figure 2, which depicts the ground-surveyed map, Landsat-based maximum likelihood classification results, and a representative Landsat field boundary overlay used to keep track of individual fields.

The Landsat classified crop identification data derived from this analysis were used to generate a 1973 water demand prediction for the study area. The results of the "crop-specific" water demand prediction are given in Table V, and compared with conventional field-based estimates. The Landsat-based predictions are very comparable with field-derived estimates, especially with an acknowledged ±5 percent variance in canal record data. Of interest is the 7 percent difference in accuracy between the Landsat "crop-specific" water demand prediction (95 percent) and the Landsat cropland water demand prediction (88 percent). These figures correspond well with the results of an analytical study previously conducted by the authors which documented the relative importance of cropland statistics versus "crop-specific" information on water demand predictions. In this study the "crop-specific" information improved water demand prediction accuracies by 6 percent.[18]

Approximately 1,000,000 acres are now irrigated in Kern County, and another 700,000 are potentially irrigable. The countywide crop value for a section of land is about $500,000 (average crop value of $780 per acre, at 640 acres per section). In principle, for each 1 percent of increased efficiency in the application of irrigation water that results from the use of improved data provided by remote sensing techniques to the hydrologic model, approximately 12.5 additional sections could be brought into production. An addition of this magnitude would represent a

"gaussian" distributions are assumed to exist. For further information see Robert M. Haralick: Glossary and Index to Remotely Sensed Image Pattern Recognition Concepts, *Pattern Recognition*, Vol. 5, 1973, pp. 391–403.

[18] Estes, Jensen, and Tinney, *op. cit.* [see footnote 9 above].

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TABLE V—CROP-SPECIFIC WATER DEMAND PREDICTION, NODE 199 WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, KERN COUNTY, CALIFORNIA, 1973

METHOD OF WATER DEMAND PREDICTION	PREDICTION ACCURACY (*percentage*)	WATER DEMAND IN ACRE-FEET					
		Total	Barley[a]	Cotton[b]	Melons[c]	Safflower[d]	Sugar beets[e]
Type of crop							
Water district inventory	96	9,966	444	7,196	1,024	433	809
Landsat multidate inventory	95	9,910	464	6,946	1,215	433	852
Cropland							
Landsat multidate inventory	88	11,742[f]					
Canal records	100	10,428[g]					

[a] The irrigation rate for barley is 1.10 acre-feet per year.
[b] The irrigation rate for cotton is 3.13 acre-feet per year.
[c] The irrigation rate for melons is 2.86 acre-feet per year.
[d] The irrigation rate for safflower is 2.85 acre-feet per year.
[e] The irrigation rate for sugar beets is 3.33 acre-feet per year.
[f] Prediction based on the countywide average irrigation rate of 3.38 acre-feet per year.
[g] California Aqueduct canal records are assumed to be 100 percent accurate.

crop value of about $6,250,000. Although there are alternative uses for water made available through more efficient allocation (such as leaching saline soils, or groundwater recharge), the above statistic is a conservative estimate of the potential benefit that remote sensing techniques could bring to Kern County.[17]

WATER DEMAND IN THE UPPER SANTA ANA RIVER BASIN

Like Kern County, the Santa Ana River Basin is a region where the nature of water resource allocation has far-reaching economic, social, and geographical implications. The basin has a large water supply of its own. However, the economic lifeblood of the basin depends on imported water because local supply is inadequate for both agriculture and domestic-industrial uses. The relationship between the two water supplies affects agricultural production, life-style, and per capita income.

The Upper Santa Ana River Basin lies east of Los Angeles and drains an area of 5,618 square kilometers (2,248 square miles). Separated from the coastal Los Angeles Basin by various hills, faults, and mountains, the only drainage outlet of the basin is the Santa Ana River, which flows through Orange County (Fig. 3). Effective precipitation (annual precipitation minus evapotranspiration) in this semiarid basin is 7.6 centimeters (3 inches), and the mean annual temperature is 17°C. (63°F.). A series of litigations during the past twenty-five years between lower basin Orange County and upper basin Riverside County and San Bernardino County users has resulted in a limitation on the quantity of surface runoff water that may be impounded by upper basin users. Consequently, upper basin users are not permitted to use all of the 266,000 acre-feet annually available.

THE ROLE OF URBAN LAND USE DATA IN WATER DEMAND INFORMATION

As in Kern County, water use in the Upper Santa Ana River Basin has an areal association with land use. Land use patterns and inventories are therefore valuable in estimating overall water demand and in understanding the spatial component of water demand. When changes in land use are monitored, a temporal dimension is added.

[17] This benefit level was arrived at through consultation with KCWA personnel.

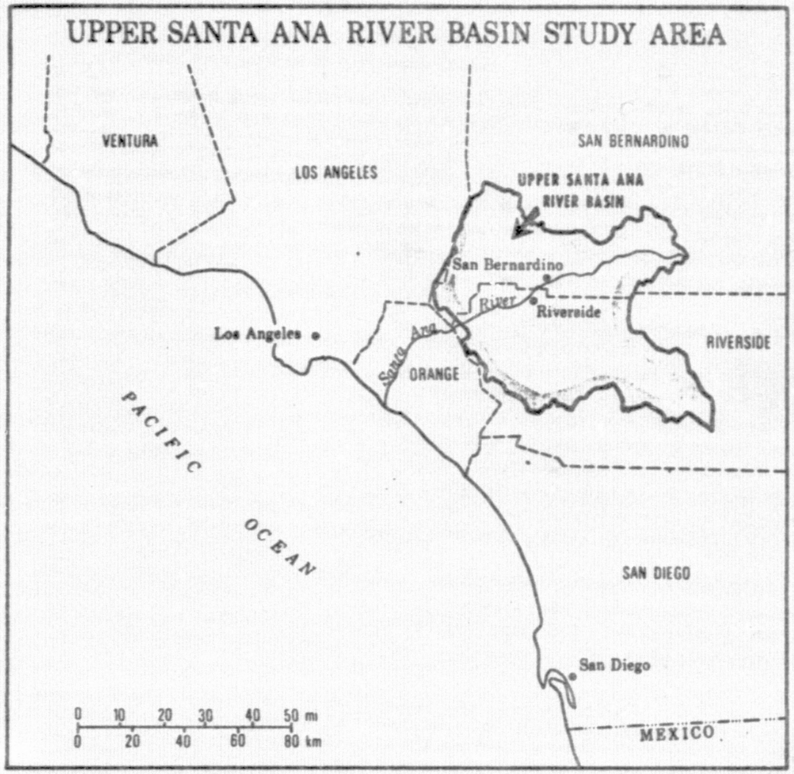

FIG. 3—The water demand study area in the Upper Santa Ana River Basin of Southern California.

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A commonly used method for estimating current unmetered water demand is to combine population and land use inventories. Estimating the demand for per capita consumption and rural land use consumption of water is straightforward if one knows the population and the land use. To estimate urban water demand, many water agencies establish a gallons-per-capita-per-day (GPCD) figure for domestic and industrial uses in each water service district. GPCD uses data for annual deliveries taken from metered municipal and industrial use plus system losses, minus nonurban use, minus water sold to other utilities. Application of the GPCD figure is limited to service districts in which reliable population and delivery estimates are available.

Population for a given year is calculated from census data by deriving the number of persons per water service connection and/or persons per dwelling unit. The population must be interpolated between census years and multiplied by the number of water service accounts or dwelling units. Where census data are not available, the water agency itself provides population estimates. The accuracy of estimates clearly depends on reliable population and/or dwelling unit data.[18]

[18] Aschmann and others, *op. cit.* [see footnote 5 above].

TABLE VI—LAND USE AREA OF THE UPPER SANTA ANA BASIN, 1975

CLASSIFICATION	ACRES
Living Area	133,001
Medium density	127,941
Low density	4,561
High density	499
Industry[a]	8,372
Transportation and utilities[a]	17,640
Commercial activities[a]	11,441
Services[a]	20,281
Recreation	13,222
Cultural assembly	1,082
Resorts and parks	12,140
Agriculture	249,276
Irrigated[b]	105,000 (?)
Nonirrigated	144,276
Resources (nonagriculture)[a]	3,720
Undeveloped	992,563
Open land	457,443
Forest	318,843
Water and dry channels	39,669
Other	176,600
BASIN TOTAL	1,449,515

[a] All classes are broken into subclasses for computer tape storage. Areas of subclasses are usually too small for the computer map display shown in Figure 4.

[b] Irrigated agriculture area and location are updated seasonally through change detection by multitemporal, digital tapes from Landsat-2.

From a planning standpoint, it is important to know where people live within a census tract and where various land uses and people exist within or overlap census tract boundaries. Census tracts are not compatible with water service districts or water planning units because the engineering and economics of water distribution depend on much more than the number of people. Remote sensing techniques are adaptable to solving the water demand estimation problem because of their speed and accuracy in determining land use. Readily available software programs can integrate data from the decennial census with land use patterns obtained from remotely sensed sources to calculate the location of people, the relation of people to land use, and the areas of each land use involved. The calculations can be performed rapidly and accurately. In addition, measurement and location of areas devoted to any of several land uses can be accomplished efficiently and may be obtained in a land-use-type-per-capita format.

Population dynamics are easy to assess if two assumptions can be made. The first is that per-dwelling-unit population density within a census tract will not change rapidly. The second is that population is proportionately divided into residential land use polygons. The user can then discover the absolute change in population for a small area. The density-of-population statistic allows the total population of any planning unit such as a hydrologic subunit, a fire district, or a school district to be obtained by summing the population of all residential areas contained within that planning area. For residential areas that are split by planning area boundaries, the per capita density figure will reveal the expected number of persons in that part of the residential unit which lies within the planning area. Care must be taken to ensure that areas which are no longer residential or which contain vacant housing are subtracted and new residential areas are added. The whole procedure is sensitive to population movement or change within census tracts, across tract boundaries, or during intercensal periods. This method can be used manually or with a computer polygon overlay system. Although all of the above information may be available from remote sensing data, in areas of doubt field investigation is required to determine the exact nature of the change within a residential area.

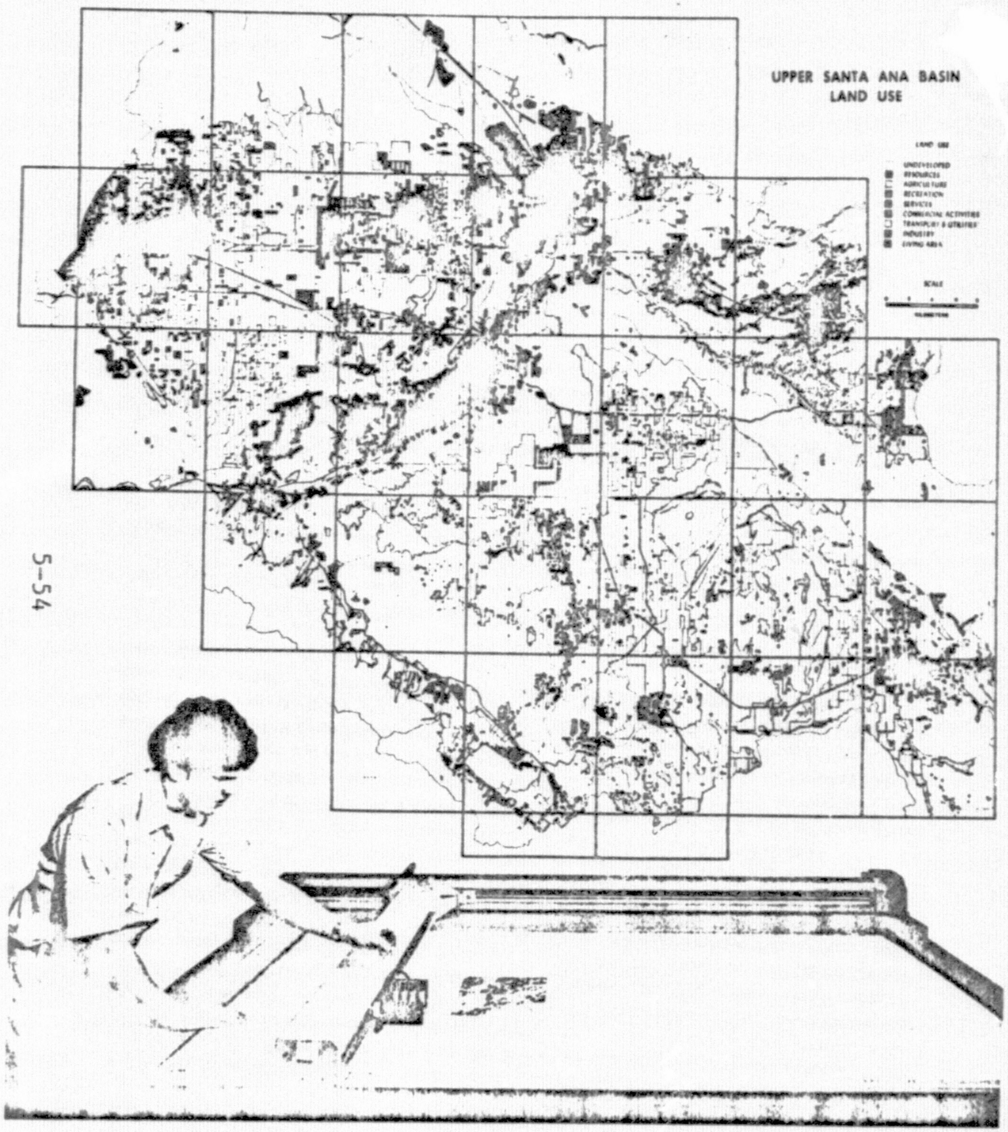

FIG. 4—Land use in the Upper Santa Ana River Basin. All land use polygons were interpreted from color infrared photography taken by ASA U-2 aircraft, Landsat imagery, or field check. The entire map is produced by automated cartography on a flat bed plotter. Each ctangle is equivalent in area to a 7.5 minute USGS quadrangle. One such quadrangle plot is shown being reduced and plotted. Polygon reage is maintained on file in the computer for rapid recall and/or update.

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THE ROLE OF REMOTE SENSING AND INFORMATION SYSTEMS IN URBAN WATER DEMAND

Land use classifications required for calculating water demand differ from those classifications needed for most planning purposes. Urban planners often desire detailed and large-scale identification to the fifth order of the standard land use identification code (SLIC). Water resource planning agencies are concerned with a more general classification and larger area unit definition. An ideal classification system would provide sufficient precision in both rural and urban environments for all users. Table VI lists the eight classes used to determine water demand in the Upper Santa Ana River Basin. The subheadings can be matched with SLIC titles for other planning purposes.

To demonstrate the applicability of high-altitude images such as those acquired by NASA's U-2 aircraft or the use of Landsat imagery, researchers at the University of California, Riverside, have mapped the land use of the Upper Santa Ana River Basin (Fig. 4). A single spacecraft image or a few U-2 images can replace many low-altitude images and yield far less distortion for automated land use mapping. The information is organized so that area water demand statistics can be easily calculated and existing water demand models can be easily updated from subsequent imagery.

Although it is useful to produce a map in order to display results and to provide planners with a view of where future actions should be directed, an important secondary output of the mapping is the compilation of area statistics by land use classes. Once the vertexes of a land use polygon have been encoded into machine-readable form, calculation of area such as acreage-per-land-use-type is almost instantaneous. Summaries by type of land use, hydrologic subunit, or any other defined subdivision are obtained rapidly, using only modest computer facilities (Table VI).

Software research and development already under way enables single computer run updating from imagery sources in either batch or interactive modes. An off-line digitizer and an interactive terminal are all the equipment required to treat and test an updating program structure. Low-level subroutines are used to maintain the program data structure and provide a basis for a complete spatial information processing/operating system.[19]

ADVANTAGES OF AUTOMATED GEOGRAPHICAL INFORMATION SYSTEMS IN WATER DEMAND MODELS

Several observations about computer mapping of land use categories related to water demand in the Upper Santa Ana River Basin can be made. First, initial map preparation and conversion to machine language require an average 0.13 man-hours per polygon (a 7.5 minute USGS quadrangle averages 190 land use polygons), or approximately 25 man-hours. Average plotting and computer-processing costs are about $140 per quadrangle (1:24,000) and represent the same time/cost factor as manual land use data compilation. However, when the land use data are extracted from aircraft or spacecraft imagery rather than from field survey, the time saved in gathering field data is often days or weeks, depending on the complexity of the area being mapped. Second, the savings in time and labor become significant once the data are analyzed and in machine-readable form. This information can be cross-correlated with other data such as income, ethnic characteristics, or whatever planners may need. Portions of the map can be reproduced quickly at other scales. Most important is the ability to quickly produce statistics such as acreages or hectares of various land use codes or combinations of land use codes. Third, benefits are greatly increased when updating procedures are necessary. In order to edit a map to make changes, only those polygons affected and the land use classes modified need be updated. Preliminary studies indicate that approximately 20 man-hours will provide machine input data for a map update. Experience with water agencies using similar systems indicates that manual updating procedures may require as many as 200 man-hours. It

[19] Steiner and Salerno, *op. cit.* [see footnote 5 above].

should be borne in mind that the minimum cost for hardware is $15,000. The land use map of the Upper Santa Ana River Basin shown in Figure 4 represents a potential savings of 5,400 man-hours.[20]

Perspective

Models capable of structuring, synthesizing, and producing viable user-oriented urban and agricultural water demand data over large areas are still in a research and development stage. The examples discussed herein, however, indicate that a significant remote sensing data generation potential now exists capable of providing the information required to improve the efficiency and increase the operational utility of such models. Although initial results appear encouraging, a number of lines of research are still needed. For example, investigators must continue to interact to identify the basic structure of water demand prediction models. Users need to define as precisely as possible the functional, spatial, and temporal information needs of their models. These data should then be viewed in terms of the socioeconomic and political constraints under which the models must operate. Second, the capabilities of various remote sensing system configurations to provide important information must be evaluated.

The ability to combine data on large areas from a mix of sensor platforms which acquire information at a variety of scales, spectral bands, and temporal sequences is an important step in producing useful information. Indeed, without the data provided by remote sensing, large-scale water demand modeling becomes essentially an attempt to project historical trends into future scenarios. With the capabilities provided by remote sensing, the potential exists to continually sample current information for both short-term and long-range water demand forecasting.

As population continues to increase, the need for accurate, timely water demand information becomes more pressing. Based on research results to date, remote sensing will have a significant impact on upgrading both the speed and the accuracy with which water demand predictions are made. Moreover, remote sensing techniques and methodologies have the potential to provide data which can improve water resource management at the local, regional, national, and international level.

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[20] The automated land use mapping system was researched and developed by Claude W. Johnson and David H. Nichols, Department of Earth Sciences, University of California, Riverside. The research was supported by the National Aeronautics and Space Administration, the Office of Naval Research, the National Science Foundation, and the United States Geological Survey.

Chapter 6

REMOTE SENSING IN CALIFORNIA: SOCIAL ASPECTS OF TECHNOLOGY TRANSFER AND ASSESSMENT

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PREFACE

Background

For the Social Sciences Group, this report concludes over seven years' involvement with the University of California's Integrated Remote Sensing Study. Anyone familiar with the effort knows that the Integrated Study has been far more than an investigation of methods for measuring and monitoring California's earth resources. Not only has the research made substantial contributions to the frontiers of remote sensing techniques; it has also contributed to the development of many individuals who now are playing key roles in the technology's transfer and continued evolution. Some of these people occupy important positions in government or academia; others are members of resource agencies or private industry.

Another distinguishing feature of the Integrated Study has been its strong user orientation. Since much of the research has focused on California's water resources, the project's investigators have paid special attention to the activities of the State'e water managers. This focus has been far from narrow. Water and water-dependent industries such as food and fiber production dominate a large part of California's (and also the nation's) economic life. Findings derived from technology applications in the water domain thus often hold implications for natural resource management more broadly defined.

Role of the Social Sciences Group

In most cases where a new technology is undergoing scrutiny, the emphasis is on the *what* rather than the *how*, *why*, and *whether*. Preoccupation with the purely technical aspects is probably based on the erroneous assumption that these are the most difficult and perhaps the most important part of a technology transfer process. The expectation is that once the hardware is adequately developed, the rest is easy. No such reliance on singular technological fixes has plagued the Integrated Study. Since the project's inception, our Social Sciences Group has been examining the institutional dynamics, social environment, political ramifications, and economic consequences surrounding applications of remote sensing technology.

We see ourselves as forging and reinforcing linkages between a community of technical specialists and a community of resource managers. We are committed to performing realistic assessments of a new technology's developing applications without presumptions about theoretical or methodological breakthroughs. Our cross-fertilization efforts are carried out in tandem with remote sensing scientists participating in the Integrated Study. But while much of their effort is aimed at developing products useful to resource managers, we are interested more in the *process* through which such products are ultimately made useful and transferred to the users.

Role of the Procedural Manuals

With the objective of encapsulating the results of seven years' work so they could be communicated readily and, hence, serve as guidelines to forthcoming applications, our technical colleagues have been developing a series of procedural manuals. Each manual deals with some specific way in which remote sensing techniques can be used advantageously on water-related resource problems. We agreed to supplement these technical manuals with a companion social sciences document. Its purpose would be to set forth some of the important social, political, and economic dimensions we have encountered during our exposure to real-life exercises in technology transfer and assessment.

Use of procedural manuals necessarily depends on their subject matter and intended audience. In most cases, the manuals can be used to greatest advantage when combined with other means for adapting the procedures. A manual used in isolation is unlikely to approach the value of a manual used in conjunction with supplementary training, technical assistance, and previous experience. We anticipate our social science contribution will work best in the latter context. In contrast to the technical manuals, which emphasize specific approaches, our document is intended to complement a broad range of remote sensing applications.

1.0 INTRODUCTION

Technology is never transferred within a social vacuum. This is especially true of a "decisional" technology like remote sensing, i.e., one that provides know-how to diagnose complex problems and to formulate alternative solutions. Ostensibly, remote sensing is concerned with measuring natural resources and phenomena in the "physical" world. Yet we find remote sensing to be a collection of techniques that depend to a considerable degree on "social" resources: e.g., skilled people, capital, institutions, and information. Thus when we talk about transferring remote sensing technology, we are dealing mainly with the social and conceptual spaces surrounding natural resources and physical space phenomena.

Public resource management, by its very nature, is a complex composite of economics, law, history, culture, politics, power plays, sociology, policy, short-term expediency, and long-term husbandry. As a result, the management of public resources can be as subject to the vagaries and vicissitudes of the social climate as to physical laws or to the rules of management science.

Basic Terminology

Several terms merit clarification at this point. "Technology" is often defined as the systematic application of scientific knowledge. Correspondingly, "technology transfer" is the sum of those activities through which the knowledge is applied to resolve problems. Those persons or organizations on the receiving end of this process are usually called the "users", while those on the originating end are known as technology "developers" or, occasionally, as "pushers". Likewise, the process of technology transfer is sometimes viewed as a conveyance through which research investments are converted into social payoffs. Those heterogeneous methodologies used to forecast and evaluate such impacts are part of what is called "technology assessment".

Approach

The foregoing concepts provide convenient categories for insights derived form the "living laboratory" that was the Integrated Study. We divide our observations into four sections that consider: (1) the technology of remote sensing; (2) the user community; (3) the factors implementing and impeding the transfer of remote sensing technology; and (4) the methodology of technology assessment as it applies to remotely-sensed information. In each section we attempt to juxtapose abstract, often imaginary, popular preconceptions with experiences taken from actual case examples.

2.0 THE TECHNOLOGY

With the unique perspective of one who has shared their vantage point, former astronaut Russell Schweickart has described earth resources satellites as harvestors of the earth's "information crop" of reflected radiance. "Our challenge," he remarked in a NASA Symposium, "is to learn to harvest and use this crop intelligently."[1]

General Characterization

Remote sensing may be characterized as a field where many of the information harvesting tools are undergoing development. Taken in its broader aspects, a remote sensing system such as Landsat represents the coordination of orbiting satellites equipped with sensors, the hardware and software of transmitting imagery to earth, and land-based facilities for receiving, processing, disseminating, and interpreting the resulting data.

Distinctions should be made, however, between the technology *per se* and its fruits, i.e., the data therefrom. This differentiation may seem obvious but it is one that is frequently overlooked by two contradictory categories: the technical experts familiar with remote sensing, and the lay public so totally unfamiliar that it sees either pretty pictures or colored blobs as meaningless as the inkblots on a Rohrschach Test. In other words, technical people know too much and the rest of us know too little.

The "technology" of remote sensing also encompasses an assortment of tools that are used to modify, measure, and massage the original data into a form usable by resource managers. Information used in their decision processes is more likely to come from a black-and-white page of statistical variances than from a false-color infrared photograph. The fact that a collection of tools is required to produce the information means that remote sensing practitioners are heavy borrowers from more established disciplines. Familiarity with remote sensing techniques does not, however, create new professionals. Instead, such skills can augment the know-how of existing resource managers, whether they be foresters, hydrologists, or geographers.

A caveat is necessary, though, to caution those whose romance with the tools and techniques of remote sensing might blind them

[1] Russell L. Schweickart, "Future Remote Sensing Programs", In *Proceedings of the NASA Earth Resources Survey Symposium*, Volume II-A, Houston, Texas, June 1975, p. 79.

to some of its nuances. All useful remote sensing applications require a subtle blend of technique and judgment; selecting the right blend for any particular application is and probably will remain something of an artform.

Origins and Legacy

The origin and development of satellite technology are germane to the use of remote sensing tools since they are an intrinsic part of the matrix of acceptance variables. With a history that links military surveillance and space exploration, satellites carry a heritage that influences perceptions and may prejudice acceptance as well. Ancestry in the military encumbers the technology with a "spy-in-the-sky" taint; space parentage ascribes a "pie-in-the-sky" label, especially when vague promises of prowess are served up as proof of performance.

While NASA enjoys public respect for having been a fulcrum of scientific and technological achievement, it also bears several stigmata: first, for being the favorite whipping boy of the demagogues, short-sighted and over-zealous in their application of cost-benefit calculations to public spending and, second, for symbolizing "high" and, therefore, esoteric technology.

Against this backdrop, there is the predictable overlay of rivalries and philosophical differences among NASA headquarters and its eleven field installations, between supporters of outer space missions and earth resources applications, and within centers that favor R&D work at the expense of groups interested in technology transfer problems. Furthermore, within the earth resources domain, questions are often raised about NASA's commitment to experimental or operational system configurations, just who should be benefiting from such programs, and whether portions of the activities might be administered better by some other agency.

Fundamental Elements

Despite the context, most remote sensing activities share a common set of basic elements. Remotely-sensed *imagery* is an element fundamental to the others. Combinations of orbital, high-flight and low altitude imagery often provide the "base map" to which ground data points are calibrated. In addition to other materials, all projects involve *equipment* of some sort, ranging from simple stereoscopes to zoom transfer scopes to interactive computers. Large projects, because of their many data points, are more adequately suited to automatic analysis methods.

All remote sensing projects, regardless of scale, include *repetitive tasks*: e.g., digitization, stratification, classification, and interpretation. The relatively expensive process of gathering ground data usually can be reduced significantly with the help of sampling procedures. This requires the use of *statistical procedures* particularly at a project's front end (to prepare the sample design) and rear end (to analyze the resulting statistics).

Performance of remote sensing tasks in turn requires *special training*. Skill shortages at any level -- biostatisticians to do the statistics, hardware and software people to repair or program the machines, interpreters familiar with resources in the study area -- can severely handicap any project. Such shortages can affect anyone, even private contractors who sell their technical assistance for a living.

Beyond performance considerations, the experimental mode of most projects makes *evaluation* of results a necessity. Yet meaningful evaluation of the data produced in remote sensing applications is frustrated by the difficulty of measuring the value of information. The dilemma presented by information that we do not know how to evaluate is discussed further in the section on technology assessment.

Any attempt to assess the value of satellite-derived information for solving real-world problems first requires a thorough understanding of the *decision context* in which the results are to be used. This element, long the focus of our Social Sciences Group, is concerned with revealing the assumptions, values, intangibles, and barriers that are likely to complicate remote sensing technology transfer processes. Since remote sensing techniques often are able to supply only a slice of an agency's pie of information needs, it is essential to know how the pieces fit together.

3.0 THE USER COMMUNITY

Locating a community of "users" is a fundamental challenge for those who are familiar with the technical side of remote sensing. Although firmly embedded in the lexicon of the "technical community", the very term "users" may suggest to outsiders some sort of illicit addiction. Instead, "user" is just another example of technologists' shorthand that conveys a false sense of precision. It is an elastic catchall that is stretched to include both real and ideal technology-using possibilities.

General Characterization

Closer inspection may reveal a "user agency" to be actually a potential user, or to contain only a solitary model manipulator or part-time student whose duties might be construed as putting the technology to use. The word has additional ambiguity when mixed with the vocabulary of governmental agencies who consider themselves to be working for a clientele of users, or when it refers to technical community members who "use" remote sensing data in their research projects.

Recognition that the "user" rubric is a single concept representing a continuum of realities helps explain some of the apparent gaps between the words and deeds involving remote sensing applications. In the water resources area, most organizations considered part of a remote sensing user community more appropriately could be described as "potential users". Yet even this term has its gradations, as Integrated Study participants have seen. Several years' involvement in research projects can change remarkably the disposition of a potential user agency toward a new technology. How far along the agency comes in actually using the technology depends on a huge number of factors -- political, economic, behavioral, and others.

Profile of Users

Sales of Landsat data from the EROS Data Center in Sioux Falls show that the largest volume of data products are purchased by private industry and federal agencies. Industrial users, particularly those in the business of extracting petroleum and minerals, are probably making the greatest "use" of remote sensing data products today. Satellite-derived information is viewed as a new "prospecting" tool, especially valuable in upgrading surface geological maps.

Users interested in the data for applied research purposes comprise another large class. LACIE[2] has been by far the largest of a group of many projects that are geared toward a sort of "usage" that is tentative and experimental. Some "users" are mainly collectors. Agencies and foreign governments sometimes maintain standing orders for imagery even if they have no immediate use for it, while individuals, urged on by magazine advertisements, may simply wish to see satellite photos of their home towns.

Users of remote sensing information, like the raw data users

[2] Large Area Crop Inventory Experiment (LACIE) has been a multi-year joint project between NASA, the U.S. Department of Agriculture, and the National Oceanic and Atmospheric Administration (NOAA) aimed at testing the effectiveness of Landsat in delivering information useful for predicting global crop production.

themselves, can be arranged along a continuum of complexity. One pre-Landsat hierarchy of uses[3] characterizes progress toward applications objectives in six stages of activity: *identify, map, monitor model, predict,* and *manage*. Within this framework, the mapping activities of users in extractive industries constitute intense development of relatively simple applications. Applications to dynamic resource phenomena like crop production are examples of relatively complex uses that still require a lot of development work. Monitoring and change detection activities, in other words, often represent a level of use several magnitudes more complicated than basic identification and mapping functions.

This distinction between types of uses helps explain the reluctance of resource managers to commit themselves prematurely to a still speculative source of information. Complex applications need extended development time, and users have little assurance that existing federal earth resources programs will continue much beyond the technology demonstration phase. Implementation of new procedures also requires the aid of specialized equipment and trained personnel. Furthermore, many adjustments must be made before satellite-derived information can blend with the decision processes of most natural resource managers.

The interest of different types of data users complicates the adjustment process. Generally, scientists involved in research are inclined to want relatively unmolested data so they can draw their own conclusions about discrepancies. Resource managers, in contrast, prefer to have their data reduced to bear directly on decisions confronting them. Extraneous information only confuses their tasks.

State and Local Users

Of the user groups capable of providing broad ranges of experience, few can offer a greater variety of resource management functions and approaches than state and local governments. Yet to justify the expense of technology demonstrations solely on the breadth of experience to be gained is not enough. Development of state and local user interest in remote sensing applications is important for two other reasons as well: (1) cooperation of non-federal governmental units is indispensible in many natural resource planning efforts, and (2) state and local agencies provide a vital forum linking resource policy questions and public response.

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[3]George Zissis, Klaus Heiss, and Robert Summers, *Design of a Study to Evaluate Benefits and Costs from the First Earth Resources Technology Satellite (ERTS-A)*, Report No. 11215-1-F, Willow Run Laboratories, Ann Arbor, July 1972, p. 37.

The first point reflects the realities of intergovernmental relations and resource issues in this country. Many state and local agencies harbor suspicions about each other, but they usually distrust federal government agencies even more. State and local agencies are especially sensitive to federal incursions into what they consider to be their discretionary domain over natural resources.

Without the support of lower governmental levels, federal plans concerning energy, water, timber, agriculture, or other resources can be subject to erosion and emasculation. Remote sensing is subject to similar pressures. If centralized only within the planning apparatus of large federal agencies and industrial organizations, the technology will fail to achieve its potential as a tool for integrating diverse bases of resource information.

The second point buttresses the first: public resource planning should involve the public and this is best accomplished through lower levels of government. Mistrust between governmental units is insignificant when compared with public mistrust of all levels of government. In some circles, governmental planning of any sort is viewed as outright "socialism".

Moreover, people perceive that most government efforts to include the public in their planning processes are a sham. The question asked most often by the citizens who attend such meetings usually is: "What are your plans going to do to me?" If remote sensing is to overcome its association in the public mind with "spy satellites" and expensive space "spectaculars", then it needs to be integrated with resource planning processes at the grass roots level of state and local government.

User Concerns in California

Accomplishing a high degree of integration between satellites and planning processes, if our experience is a guide, requires a full-time effort that extends over many years. The point has not been lost on California state officials who are familiar with the experiences of various state agencies in applying remotely-sensed information. A member of the Governor's Office of Planning and Research recently described some of the realities involved in transferring Landsat technology to California agencies:[4]

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[4]William L. Kahrl, Director of Research, Governor's Office of Planning and Research, State of California, "Overview of California's Approach to a Statewide Remote Sensing Program," address delivered to the National Conference of State Legislatures Remote Sensing Workshop, Cal-Neva Lodge, Lake Tahoe, November 8, 1977.

> The problem of achieving ongoing applications of Landsat technology involves not the adoption of a system but the conversion of our existing systems. For this purpose, it is probably not sufficient that the technology is economical; it must be inexpensive enough to justify trashing another system. It is not sufficient that the technology be useful, it must be uniquely so. It is not sufficient that the technology is simply efficient, it must be better than what we are doing already.

Water Resources Perspective

California's water resources, as emphasized early in the Integrated Study, provide an excellent vantage from which to scrutinize remote sensing applications. "Water," Leonardo da Vinci once observed, "is the driver of nature." In California especially, it is also a driver of human affairs. The importance of water in natural resources and social processes helps extend the validity of lessons learned while applying remote sensing techniques to water supply and demand problems.

Although the water resources applications dealt with in the Integrated Study are but a tip of a much larger R&D iceberg,[5] we feel many of the resulting insights can be of use in future projects designed around user needs. In the remainder of this section, we examine those insights that deal with agency information requirements.

Water Management Information Needs

The sort of information required by water managers (or by any other resource management activity, for that matter) follows directly from the kinds of problems and alternative solutions perceived, and from the various risks, uncertainties, and constraints present. Increasingly, the sorts of problems water managers must face are tangled

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[5]See, for example, American Water Resources Association, *Remote Sensing and Water Resources Management*, Urbana, Illinois, June 1973; and Albert Rango, "Applications of Remote Sensing to Watershed Management", Goddard Space Flight Center document X-913-75-86, Greenbelt, Maryland, June 1975. Experimental applications and demonstrations of earth resources satellite capabilities include among others work in snow mapping, flood assessment and floodplain mapping, surface water inventories, hydrologic land use analysis, physiographic characterization, watershed modeling, and determination of soil moisture.

with issues concerning energy consumption, food and fiber production, land use and transportation policy, environmental protection, and social justice.

The decision choices of water managers, in other words, affect a wide range of people and groups with interests that transcend basic water development and operation issues. Such groups understandably place differing values on the consequences of alternative decisions. Since different groups of advocates have varying access to the decision-makers and their information concerning consequences, water managers find themselves pressured to develop and test planning systems using information that is more comprehensive, publicly visible, and "value-neutral".

Broader objectives and multidisciplinary planning requirements thus provide many of the stimuli to investigate new techniques for handling water planning information. The availability of large-scale data handling capabilities is another stimulus. Computer models that simulate physical, economic, and environmental conditions can be found within most of the larger water management agencies, although agreement on their utility is harder to find.

Meanwhile, water agencies rely on a variety of basic information just to get through year-to-year operations: meteorological and hydrological data concerning snowpack, runoff volume, and stream flow variability; geologic and vegetative characteristics of watersheds; water use and water quality data for irrigated agriculture, recreation, and other uses; soil moisture and ground water variations; and flood potential and damage extent should flooding occur.

Technology Adaptation Realities

Zealous members of the remote sensing community look at the information requirements of water management organizations and see their satellite data blending harmoniously with terrestrial water models. Such optimism overlooks several facts of life within the agencies that use such models, namely that:

(1) Watershed models capable of using satellite information are in very preliminary stages;

(2) Implementation of any major water model takes many years;

(3) It is often difficult to get the right people interested in new data manipulation methods;

(4) Few agency personnel are likely to be familiar with remote sensing techniques;

(5) Most remote sensing digital equipment is expensive by agency standards; and

(6) Operating costs for analyzing large areas are also relatively high.

Much of the work performed under the Integrated Study auspices illustrates that there are ways to surmount these problems. Small-scale research demonstrations are often able to penetrate organizational interstices that would impede large projects. More importantly, continuing involvement over a period of years nurtures a deeper understanding of the problems and possibilities in transferring new methodologies.

Applications Examples

To illustrate the realities of adapting remote sensing technology to the information requirements of water managers, we have selected three applications examples: 1) the snow survey work of the California Department of Water Resources (DWR); 2) the Kern County Water Agency's water demand modeling effort; and 3) general management concerns about drought conditions.

- Snow survey. One of the greatest dilemmas facing a manager of snow survey operations is deciding which technological baskets should carry his scarce supply of eggs. DWR's Snow Survey Branch employs a well-established watershed indexing system, based on samples from snow courses and aerial markers, but it also is experimenting with modeling systems which use satellite photos and computers. The objective of the program is to provide water system operators with timely runoff information that will allow them to assess their risks better. Yet even with the best possible information, uncertainty about future weather accounts for the greatest source of error in forecasting the snowpack's "rate of ripening".

  In commenting upon the Integrated Study work on snow water content measurement, snow survey experts acknowledged that the statistics developed often told more about the hydrology involved than the forecasts. Multidate analyses of watershed characteristics will reveal areas of variability within snow water content strata, thus making it possible to more judiciously allocate snow courses. Ground substantiation is likely to remain one of the more costly elements of snow survey work, regardless of whether indexing or continuous modeling methods are employed.

- Water demand modeling. Managers of large farming operations often would like to know how greater water demand prediction abilities could expand their management options. Their decision problem in terms of remote sensing could be stated thusly: what would more accurate, more timely, and less costly information on water usage allow them to achieve? Should they inject, spread, or sell the water? Should more land be brought into production? If so, in what crops? The Geography Remote sensing Unit's work on salinity and perched water in Kern County[6] has shown also that farmers often lack information on the real extent of such problems, and would like to know where to bore wells and locate canals.

- Drought. The severity of California's recent drought[7] revealed both water managers and farmers to be among the world's biggest gamblers. With the state's massive water system nearly depleted, many farmers had to drill deeper into rapidly declining water tables. Drought-weary water managers and farmers are obviously more interested in replenished water supplies than in satellite data.

Yet, when asked directly about the information requirements, those in the business of maintaining state irrigated agriculture are fairly specific: they would like to know how many acres are planted; how much water is available from surface, soil moisture, and groundwater sources; how much water is used; and what the health status is of the state's fruit and nut trees. Current information on these categories is especially useful in assessing the effects of a drought.

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[6]See John E. Estes, *et al.*, "Remote Sensing Detection and Monitoring of Perched Water Tables in Kern County," Chapter 3 in Robert N. Colwell, *et al., An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques,* Semi-Annual Progress Report, NASA Grant NGL 05-003-404, Space Sciences Laboratory, University of California, Berkeley, May 31, 1976.

[7]For further description of the drought, see: State of California, Resources Agency, Department of Water Resources, *The Continuing California Drought,* August 1977; Anne Jackson, "How California Life Will Change as a Result of Two Parched Years", *California Journal,* April 1977, pp. 111-122; and Ida R. Hoos and James M. Sharp, "Impacts of the Drought on Water Management in California -- A Socioeconomic View", Chapter 6 in Robert N. Colwell, *et al., op. cit.,* May 31, 1977.

4.0 TECHNOLOGY TRANSFER

Technology transfer has been described by one agricultural researcher as "a complicated process, interlaced with communication strings, shaped by a continuum of knowledge, and pulsating with research findings and user demands".[8] The Integrated Study, viewed in its entirety, can be seen as a continuing effort in technology transfer. It comprises parallel threads of research, research assimilation, and application of research to California resource problems, particularly in the water area.

Technology Transfer Payoffs

Technology transfer often is regarded as a process through which investments in research and development are transformed into social payoffs, usually measured in economic terms. In the case of water resources research, however, the majority of new technological developments have few immediate and readily demonstrable payoffs.[9]

Experience from the Integrated Study only superficially confirms this observation. Evidence of large payoffs are not yet visible in the current operating budgets of those agencies which have been project participants. Yet it is relatively easy to identify higher-order payoffs represented by individuals whose knowledge, capabilities, and careers have been changed by association with the project.

Related concepts

Technology transfer of the "person-embodied" sort is essential if an ongoing program of use to resource managers is to be sustained. In addition to the human element, remote sensing also contains portions of "product-embodied" and "process-embodied" technology. Outside of specialized data reduction and image enhancement hardware, the product component of remote sensing needing transfer is small. In contrast, transferring the process by which useful information is extracted from raw data can be a large task, depending on the application involved.

Usually the direction of transfer makes a difference on what

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[8] K.E. Saxton, "Technology Development and Transfer for Natural Resources Management," *Journal of Soil and Water Conservation*, May-June 1977, p. 124.

[9] Universities Council on Water Resources (UCOWR) Techology Transfer Committee, *Water Resources Technology Transfer, A Guide*, available from the Office of Water Research and Technology, U.S. Department of the Interior, Washington, D.C., January 1977, p. 6.

is transferred. Some of the Integrated Study's findings have been transferred horizontally, between research groups, while most efforts are aimed at vertical transfer, directed from research toward application.

The fact that application of research findings almost never is achieved in a single step explains why technology transfer is considered a process. The process through which an innovation is communicated from one individual to another through an organization is termed "diffusion". Correspondingly, the procedure by which new information is actually perceived, internalized, and used has been termed the "adoptive process". This has been portrayed as involving five stages along an S-shaped learning curve consisting of (1) awareness, (2) interest, (3) evaluation, (4) trial, and (5) adoption.[10]

Sometimes preceding and usually following technology transfer is the process of "information dissemination". While this activity is aimed at stimulating user receptivity by creating an awareness of the new technology, it can backfire when poorly handled. "Full dissemination and use of research," according to a recent Office of Water Research and Technology report, "requires an understanding of social systems by technology tranfer specialists and prospective users, and is necessary before effective communications of new research and innovation can occur."[11]

Throughout the Integrated Study, our Social Sciences Group has attempted to provide this kind of understanding. In the remainder of this section we discuss several topics aimed at promoting understanding of remote sensing technology transfer processes as we have observed them. We consider, in order, preconditions for successful technology transfer; elements which help implement technology transfer; impediments to transfer, both user-related and technology-related; and potential pitfalls.

Preconditions for Transfer

Even a cursory exposure to remote sensing applications is sufficient to learn that the technology will not transfer itself. It is occasionally complex, it sometimes requires specialized equipment, the people doing it require special training, and each application must be tailored to fit the user's particular problems.

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[10] UCOWR, *op. cit.*, from Everett M. Rogers, *Diffusion of Innovation*, The Press of Glencoe, New York, 1962.

[11] UCOWR, *op. cit.*

Nevertheless, one does not have to look far to find examples of applied remote sensing research that assume away such difficulties. Excessive preoccupation with the technical "trees" of applications can obscure whole forests of resource problems.

Since problem resolution is the usual end product desired from the application of new knowledge, familiarity with a user's information requirements and decision processes is essential to direct the technology toward real problems. The whole transfer process is greatly facilitated, in other words, when technology transfer objectives are coincident with the user's *perceived needs*.

A closely related precondition for successful transfer is the user's stake in the effort. In those cases where the user has a *vested interest* in a positive outcome, the transfer effort is likely to proceed more smoothly. Such an interest may be created when the user agrees to contribute personnel, facilities, or other resources to the project, or when the user is able to participate directly in selecting the area for technology application and in evaluating the resulting outcome.

Obviously, users are likely to have greater interest in participating in demonstrations of technologies they already know something about. With remote sensing techniques especially, early user *awareness* can greatly expedite successful applications. Initial exposures to the technology may come about through deliberate information dissemination, or by reputation from the experiences of other users.

Progress from a state of awareness to a state of interest and eventual involvement is much assisted by *motivated individuals* within the user organization. These people are often ahead of their associates in formulating problems and asking the appropriate research questions. Their key role as intermediaries between general technical information and specific applications of it in new operations has earned them a reputation of "technological gatekeepers".[12] User organizations fortunate enough to employ even one such individual have significant advantages in shortening their path toward successful transfer of a technology like remote sensing.

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[12] See: Thomas J. Allen, *et al.*, "The International Technological Gatekeeper," *Technology Review*, March 1971, p. 1; discussed in Dennis Goulet, "The Paradox of Technology Transfer," *Bulletin of Atomic Scientists*, June 1975, p. 45; and Edward B. Roberts, "Generating Effective Corporate Innovation," *Technology Review*, October-November 1977, p. 27.

Implementing Elements

Attention to the right factors can often reduce the distance between promising innovations and useful applications. We consider here a cluster of elements which affect remote sensing implementation efforts. These elements are really multidimensional labels that reduce to near platitudes if described in just a single dimension.

Most everyone will agree, for example, that sustained person-to person contacts between technology developers and users are essential to successful transfer efforts. Similarly, each element has its reciprocal: if improved communication linkages foster transfer processes, then the same processes are likely to be inhibited without them. All these elements acquire greater meaning when qualitative dimensions are added.

- Communication. Feedback between participants is vital for sustaining transfer of an information technology like remote sensing. Tailoring applications to a user's unique information parameters is a job that requires intense communication in a variety of modes. Personal contact is clearly indispensible for establishing and nurturing the sort of credibility between individuals needed to transfer complicated technologies. Geographical arrangements often determine how personal contacts are made and maintained.

  Other media are also useful for transferring research findings but they must fit the target audience. Public relations media -- news releases, magazine articles, broadcasts, and the like -- are geared to general audiences, whereas newsletters, trade journals, displays, and seminars are more appropriate for specialized audiences.

  User manuals, such as those associated with the Integrated Study, are even more detailed and specific in content. Specialized manuals are usually insufficient by themselves as communication tools. They have greater utility when incorporated into technology transfer "packages" that include additional support and technical assistance. All these communications, regardless of intended audience or medium, are beneficial if *simplicity* becomes their guiding principle.

- Coordination. Establishing a means for coordinating technology transfer activities involving governmental agencies becomes a necessity in larger projects. A transfer process left to the coordinating abilities of individual researchers may be too speculative for many users.

  The wide variety of possible coordinating configurations -- ranging from outside task forces to in-house top executive -- suggests some of the attributes needed for the role. Above all, such individuals should be effective translators, capable of bridging the gaps between researchers and users. Moreover, it helps if they possess sufficient authority and technical knowledge to make the kind of decisions required to keep demonstration projects "on track". A mixture of pragmatism and ingenuity is also an asset.

An Office of Water Research and Technology report describes the coordination function in mechanical terms:[13] "A transfer program may be likened to a gear-wheel whose cogs must mesh with several other gear-wheels which are already in motion. The program gear-wheel must be turning at the correct speed to achieve correct meshing without clashing."

- Continuity. It takes time to put into place an effective apparatus for communicating and coordinating a process for technology acceptance. Even then, it may still take years before a technology like remote sensing will begin to bear fruit. Disruptions in personnel and support along the way can undermine credibility and morale. Avoiding discontinuities in a long-term program of technology transfer can be made even more difficult by the normal political and budgetary cycles.

The extraordinary length of transfer processes may obscure their endpoint. "The transfer of a technology will be completed," according to one researcher,[14] "when the technology becomes generally accepted practice, or when the chief officer of a governmental unit routinely assesses available technology when presented with a problem, or when the technology is readily available in the marketplace."

- Competence. A useful premise for technology transfer activities is that there are no "experts". There are instead only individuals with varying degrees of knowledge (or ignorance) on different subjects. In most projects, technology diffusion possibilities are limited by the quantitative and qualitative boundaries of specialized knowledge and skill.

"Competence", a more inclusive concept than expertness, is one of those intangibles easier to recognize than to define. Neither technology developers nor users have a monopoly on this commodity. Much like compatibility, competence is a quality that is difficult to transplant or grow artificially. It, too, needs to be nurtured by a climate of relevance and considerable patience.

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[13] UCOWR, *op. cit.*, p. 17.

[14] Charles F. Miller, "Some Approaches to Transferring Federal Technology to State and Local Governments: The Lawrence Livermore Laboratory Experience," *Proceedings of the National Symposium on Utilization of People-Related Research, Development, Test and Evaluation,* San Diego, California, June 14-17, 1977.

- Commitment. No technology transfer process can succeed without commitment and support from a variety of directions. Commitment from political leadership is one of the most useful sources of support, but one of the most difficult to achieve. Legislators, in particular, often fear that natural resources data collection systems will turn into "bottomless pits".

  Securing the commitment of top administrative leadership within the agency can also greatly assist a transfer effort, but without sufficient "fires" already ignited within the organization's lower levels, there is unlikely to be any "smoke" at the top.

  Financial commitment from either within or outside the agency is important for sustaining the effort, although agency-contributed resources tend to generate greater user participation for the money.

  The commitment of technical expertise is another essential ingredient. Normally coming from outside the user organization, technical support requires careful supervision to keep costs in line and work consistent with user information needs.

  Finally, the moral support engendered by similar commitments of other agencies working on parallel transfer programs can be an extremely beneficial catalyst. Regular information exchanges between different user groups helps spread both technical and non-technical insights and maintain a continuity of interest.

User-Related Impediments

Once a transfer process has begun, there are a host of other conditions that influence user response toward the new technology. Here we consider one set of issues that can impede or deny success to any technology application effort: agency insecurities over the possible side effects of including remotely-sensed information in their operations.

These considerations point up the subtle distinction between *evaluation* of a technology's results and the more comprehensive notion of technology *assessment*. Side effects often escape more formalized evaluative procedures because they possess poor visibility, defy meaningful quantification, or both. Yet failure to adequately assess and anticipate such "intangibles" can be disastrous for a technology transfer effort. Implementation of any of a variety of remote sensing information systems, from the viewpoint of water managers, particularly, might be expected to raise concerns about the following sorts of changes:

- Changes in activities. Familiarity with an existing method of producing resource management information can breed contempt for new methodologies. Snow surveying work, for example, still makes occasional use of men who ski through winter snows to collect snow water content measurements. Likewise, DWR agricultural inventories require substantial field work that would probably be reduced in satellite-based systems that use sophisticated sampling techniques. For those who prefer outdoor rigor and "windshield surveys" to stereoscopes, the activity changes associated with remote sensing could diminish job satisfaction. Concerns of this type are best dealt with by implementing changes gradually.

- Changes in budget. The possibility that any savings generated by new methods would result in reduced budgetary discretion is a concern very real to agencies exploring new technologies. Such fears are likely to be exaggerated, however, since new methodologies usually require a series of budget years to achieve implementation. Probably greater budgetary dislocations are caused when outside support for experimental programs is withdrawn. Money and personnel "bootlegged" from temporary sources are often used by resource management agencies to supplement relatively inflexible budgets.

- Changes in equipment. Certainly not all remote sensing approaches are immune from "people versus machine" controversies that accompany many high technology applications. Yet of the applications investigated under the Integrated Study, most are designed to mesh with existing agency methods with a minimum of equipment changes. The manual method of snow areal extent estimation, for example, divides the resource photo into grid cells for manual interpretation. The procedure is compatible with machine-aided classification methods when and if they should be desired. Proposed crop inventory procedures follow a similar tack: outside of extra stereoscopes and acetate overlays, they use very little equipment or material not already used by DWR in their own surveys.

- Changes in information. Agency concerns that a new technology will be unable to deliver new information in the old format are frequently justified. A system for performing a statewide inventory of agricultural acreage in a single year, for example, would no doubt require broader land use categories than the less frequent but more detailed system now used by DWR. Advantages and disadvantages of changes in information scope and detail must be examined on a case-by-case basis.

- Changes in jurisdiction. A related issue involves the possibility that new information combinations might alter existing jurisdictions over information sources. Since water resources and land use information is common to several state agencies, changes initiated by one agency sometimes can affect the others. Efforts to consolidate the information-gathering activities of state agencies undergo periodic revival,[15] and it is probable that the increased availability of synoptic data will encourage greater consolidation in the future.

[15] See, for example, Legislative Analyst, State of California, "Water Resources Planning and Agricultural Water Needs," January 1973.

- Changes in public image. Any agency making greater use of imagery from earth resources satellites and U-2's should be prepared to encounter public fears about "spy-in-the-sky" surveillance. NASA's civilian space technology is rich in a military heritage that for some people transfers guilt by association to those organizations that make use of it. Farmers are often among the first citizens to voice their concern that remotely-sensed information will invade their privacy.

- Changes in skills. Increases in photo interpretative and statistical skills are almost always required to use remote sensing techniques to an advantage. Such skills are transferred through training and practice -- there are no shortcuts to competency. Fortunately, when agency personnel are already familiar with aerial photographs of resources in their respective areas, the skills transfer tasks can be simplified.

Technology-Related Impediments

User agency concerns over changes that might accompany the adoption of remote sensing techniques are one category of impediments to technology transfer. Another category relates more directly to characteristics of the technology itself. These factors can be equally influential in determining a user's receptivity to applications involving remote sensing. We list them here:

- Complexity. This point can be summarized in the axiom: "If they can't understand it, they won't use it." A user organization's pace of learning or adoption of the technology is governed by that technology's complexity.

- Specificity. The technology applications must specifically address problems faced by the user. An elaborate "mousetrap" will be of little use to an organization with plenty of standard traps or no mice. In addition, new technologies must prove themselves along the way, and the "proof" must be fairly tangible in a relatively short time.

- Availability. This term concerns the efficiency of the technology's delivery system. The speed of data availability can be critical for users with applications dealing with transient phenomena like snow areal extent or crop acreage. Unavailable or untimely data can subvert progress achieved in adapting new methodologies to user needs.

- Reliability. This concept has a dual meaning: it refers to the quality and consistency of the data as well as continuation of the data source. The second meaning lies at the core of the earth resources data "chicken and egg" problem where users are reluctant to use the data unless they can be assured of its continued availability, and where federal support for additional earth resources satellites is contingent on demonstrated user acceptance.

- Accessibility. The reference here is not to the efficiency of the delivery system but to its openness of access. Prospective users invariably ask about the secrecy associated with the gathering and dissemination of Landsat-type data. They usually are relieved to find that, unlike publicly-accessible military satellite data which require detailed personal security checks, obtaining data gathered by civilian satellites is no more difficult than ordering from mail-order catalogs. Freedom of access is axiomatic as a condition for receptivity.

- Compatibility. Potential users often are reluctant to try out new data sources if they are incompatible with familiar decision models. Compatibility is particularly important when the user is attempting to blend multiple sources or uses of data.

Potential Pitfalls

The negative counterparts of the elements which help implement transfer attempts are most visible when the attempts are viewed in hindsight. We see them as potential pitfalls for most remote sensing applications that involve governmental agencies. Along with the user- and technology-related characteristics that influence receptivity, the pitfalls can be grouped among those elements that impede technology transfer.

- Oversell. Supporters of many new technologies run the risk of raising user expectations to levels beyond what current applications can deliver. No linguist is needed to note the increase in praiseworthy words used to describe the technology as one ventures up through the administrative hierarchy -- and away from the user application level.

- Overkill. This pitfall is related to the complexity problem and user concerns about changes in equipment. It often involves cases where sophisticated digital classification capabilities are prematurely applied to resource inventory problems. A "computational imperative" is thus thrust upon an agency that has yet to grow comfortable with manual interpretation techniques. A solution for cases like this are sequences of smaller projects emphasizing fundamental principles in manual formats that can be easily adapted to computerized methods, when and if they are needed.

- Undertraining. The scarcest resources in most remote sensing applications are properly-trained personnel. Unfortunately, there are no shortcuts available for creating more of them. No amount of half-day minicourses or two-week workshops can substitute for experience gained over several years of direct involvement in applying remote sensing imagery to resources problems. Furthermore, different types of training are needed for different resource disciplines and for the various functions within them.

- Underinvolvement. An agency's ambivalence or lack of sufficiently qualified or motivated personnel may seriously handicap their participation in demonstration projects. Situations like this can cause agencies to turn over too much of their project to consultants or others who lack familiarity with the agency's resource problems and information needs. The risk here is that the agency will treat the outside data manipulations as a "black box", accepting or rejecting the resulting outputs uncritically. Not only does the underinvolved agency learn little in this process, but it may overlook sources of error that could have been easily eliminated.

- Spurious evaluation. Agencies participating in remote sensing applications can sometimes find themselves caught up in a "rush to judgment" encouraged by powers far removed from the technology implementation phase. This situation can produce premature, incomplete, and incestually-validated evaluations of little use to anyone, especially the user. Agencies are very sensitive about numbers that publicize how poorly their existing information systems fare next to an experimental mode. Rarely are new technologies subjected to the more comprehensive assessments they deserve.

- Misapplication. This pitfall is a variation of the "hammer-nail" problem wherein everything begins to look like a nail if the only tool you have is a hammer. It occurs most often in cases where the user and technologists have failed to anticipate areas where the technology can be advantageously applied to solve genuine problems.

5.0 TECHNOLOGY ASSESSMENT

Isolation of a community of users and articulation of their information needs are merely prerequisites in actually applying a new technology. A full range of technology transfer issues must be resolved before any progress can hope to be achieved. These include a determination of the user's state of readiness and receptivity conditions, identification of key individuals and sources of support, and selection of appropriate methods for communicating, coordinating, and evaluating introduction of the technology. All these issues, particularly that of evaluation, are related to the larger discipline of technology assessment.

State of the Assessment Art

To call technology assessment a "discipline" runs the risk of endowing it with more maturity than it actually possesses. Although the methodology has undergone considerable evolution within the last decade, technology assessment is still in its infancy. It is really an amalgam of techniques borrowed mainly from operations research and systems analysis.

Technology assessment, in other words, basks in a borrowed glory because of a prestigious heritage in defense and space management. Most of the discipline's applications have centered on narrowly-construed problems in military, public works, or business domains. All too often, weighty conclusions are supported on a fragile base of deceptively precise benefit-cost calculations. The failure of such studies to inquire about wider social costs and benefits and their incidence on various publics sometimes leads to unfortunate effects, including popular backlashes against engineers, scientists, and public officials.

Relation to Water Resources Issues

It is no accident that much of the evaluative foundation of assessment methodology was built around water resources problems. Governmental operations in the water resources area were deemed analogous to those of private enterprise since the principal outputs of water projects -- water and power -- are salable commodities bearing market prices.

Not long ago, evaluation of water resources projects meant assessing their contributions toward objectives such as irrigation, reclamation, hydropower generation, flood control, water transport, and municipal and industrial uses. These objectives in turn often were collapsed into a single overall objective, measureable in terms of contributions to net national product. Intangible project impacts, those not readily translated into monetary units, either were neglected or minimized.

Shifts in social priorities have thrust some of the second order impacts into greater prominence. Project evaluation today often means assessing contributions to such additional objectives as outdoor recreation, regional development, wildlife conservation, scenic enhancement, and income distribution. No single standard of value, monetary or otherwise, can fit all objectives.

Relation to Remote Sensing Issues

Assessing the contributions of an information technology like remote sensing in a resource management area like water resources further expands the evaluation complexities. Decisions, decision-makers, and decision-makers' objectives lie at the heart of the matter. What ultimately counts is *how the data are used* to improve decisions.

The web of fact and fancy that has accompanied satellite remote sensing applications has also complicated efforts to assess the technology. Pressured by federal budget custodians, those developing the technology have been hampered by the ultimate necessity to justify the world-orbiting satellite system by its end product, i.e., data. Remote sensing being in essence an information-gathering tool, the conventional paradigm calls for assessment and evaluation of that product.

But here we encounter a basic problem: how to assess the value of data. Despite the highly theoretical contributions of Marschak[16] and the earnest modeling exercise by Hayami and Peterson,[17] to mention the more frequently cited references, we really do not know how to evaluate information. This is to say nothing of providing sensible answers to questions such as: what should be paid for it; who should pay; who should decide, and the like.

> The evaluation of various types of information in their own terms as contributions to knowledge of value in themselves invites ... difficulty. One cannot judge where information is appropriate, or necessary, or sufficient, or excessive, except in terms of the uses to which it will be put.[18]

To recapitulate, the fruit of the technology is *data,* but data in the abstract eludes sensible evaluation. What counts, then, is whether, how well, and to what purpose the data are used. Do they make a difference? In other words, remote sensing technology is subject to evaluation not on its capacity to produce certain end-products, but on the way those products are perceived, received, and utilized.

This is a precarious position, much like judging a sewing machine by the articles which a particular operator does or can turn out! It is also an anomalous situation that critical tests of the technology may actually lie in a future time frame and certainly outside the technical sphere. The ultimate tests of remote sensing technology

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[16] Jacob Marschak, "The Economics of Inquiring, Communicating, Deciding", *American Economic Review,* Volume 58, No. 2, May 1968, pp. 1-18.

[17] Yujiro Hayami and Willis Peterson, "Social Returns to Public Information Services: Statistical Reporting of U.S. Farm Communities", *American Economic Review,* Volume 62, No. 1, March 1972, pp. 119-130.

[18] Zissis, Heiss, and Summers, *op. cit.,* p. 9.

thus lie less in its own state-of-the-art than in the states of *other* arts.

Decision Context

User objectives and decision processes are therefore common denominators for approaching both technology assessment and utilization questions. Especially critical are assumptions concerning the extent of impacts expected from the investment in question, what impacts and affected groups lie within these boundaries, and how the impacts are valued. An understanding of the decision processes at work within the affected resources management agencies can do more than illuminate these evaluation issues: it can also help in designing a technology transfer program compatible with the objectives of the organizations involved.

While there seems to be no doubt about the importance of timely and comprehensive data, even this contention turns out to be more a matter of intuition and an article of faith than a demonstrable and defensible fact. According to another conventional paradigm, lack of information is assumed to be one of the major factors limiting "scientific" or "rational" decision-making. Conversely, better information would result in improved decisions. In the case of remote sensing, there is the further assumption that the data are available and relevant.

The fact is that many decisions in the natural resource management arena are made outside the narrow boundaries of "rational" decision-making. Conflicting and clashing interests, opposing views, jurisdictional disputes, political overtones, social and economic implications -- all enter into such decisions. As a consequence, many of the very items selected as exemplars of the "benefits" that could be realized were remotely-sensed data to be used, turn out to be at the scene of constant controversy. At those times, it is altogether and unfortunately likely that more or better data would make little difference or at best have little visibility in the final decisions.

It turns out that the qualitative elements within decision processes often are far more useful to resource managers than quantitative information. For example, information concerning the volume of potential runoff contained in a snowpack is of little use to a water manager with a reservoir nearing capacity. He must decide whether or not to open the spillway, when, and for how long. What the manager really needs is information that allows him to assess better his risks in marginal cases. This implies an improvement in the water manager's capability to handle improved forecasts. Decision-makers at the operational level, in other words, are looking for better information on the consequences they face while pursuing alternative courses of action.

Limitations of Assessment Methodology

Experience with the realities of natural resource decision-making is bringing an increased sophistication concerning the limitations of the assessment methodology. Technology assessment and its chief evaluative underpinnings (cost-benefit and cost-effectiveness analysis) share several of these characteristics:

(1) They are social *advisory* activities and do not by themselves produce policy decisions.

(2) They are filled with value judgments and assumptions.

(3) They cannot be routinized.

(4) They depend on a continuous evaluation of the state of society, since rapid changes in socioeconomic conditions can upset many of their underlying assumptions.

A heightened awareness of the inherent limits of quantitative analysis underlies much of the shift in attitude concerning assessment methodology:

> Unhappy clashes with aroused groups of ecologists have proved that when a dam is being proposed, kingfishers may have as much political clout as kilowatts. How do you apply cost-benefit analysis to kingfishers? ... In the long run the entire Cartesian assumption (that there are measurable and incommensurable quantities) must be abandoned for recognition that quantity is only one of the qualities and that all decisions including the quantitative, are inherently qualitative.[19]

Also, there is the realization that the search for a single method for performing assessments has been misguided: "The broad category of systems analysis is likely to be the central theme in any assessment. But there is no general method, methodology, or techniques yet developed for conducting a technology assessment."[20]

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[19] Lynn White, Jr., "Technology Assessment from the Stance of a Medieval Historian", *Technological Forecasting and Social Change, 6*, 1974, p. 360.

[20] M.J. Cetron and B. Bartocha (eds.), *Technology Assessment in a Dynamic Environment,* Gordon and Breach, New York, 1973, p. 285.

Moreover, there exists little assurance that different assessments will produce similar conclusions: "Since the specific methods for determining the unintended, indirect, and delayed social effects of a given technology are diverse, unrigorous, and judgmental, different teams of equal competence are likely to generate different technology assessment results -- different in emphasis and usefulness to decision makers."[21]

Emerging View

Experience with the earlier generation of technology assessment efforts has prompted a reconsideration of their role. A more mature approach is emerging that includes, for one thing, a growing consensus on what a comprehensive technology assessment should be:[22]

(1) Any assessment implies a comparison of advantages and disadvantages of a specific project or technology.

(2) A technology assessment consists of two complementary and closely interweaving processes: *forecasting* and *evaluation*.

(3) The object of a technology assessment is to distinguish between a technology's desirable impacts, undesirable impacts, and uncertainties.

(4) A comprehensive technology assessment attempts to consider all relevant aspects of a technology's impacts on society. It includes first-, second-, and third-order impacts as well as impacts on various constituencies.

(5) Technology assessment is a multidisciplinary approach, it is iterative, and it is an instrument of policy-making.

If nothing else, continuing maturation of approaches to technology assessment has produced a new humility regarding the interaction of technology and the complex systems that encompass man, society, and the environment. Increasingly, technology assessment is viewed as a means of obtaining *some* insights about the application of technology to *some* elements of such systems.

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[21] George J. Zissis and Robert B. DiGiovanni, *Remote Sensing: A Partial Technology Assessment -- A User's Report*, Ann Arbor, Environmental Research Institute of Michigan, 1977, p. 15.

[22] François Hetman, *Society and the Assessment of Technology*, OECD Publications, Paris, 1973, pp. 350-390.

Comprehensiveness is impossible; routinized approaches to different problems are unrealistic. A well-conceived technology assessment may overcome the obvious limitations of a narrowly-defined impact study or an overly-precise benefit-cost analysis, but it, too, will have limitations.

Nonetheless, an improved understanding of new technologies and their effects on social and physical systems is essential to avoid in the future many of the problems and mistakes of the past. Even though we may not know how to assess properly a proposed technological change, that should not prevent us from trying.

Assessment from the User's Perspective

The parallel objectives of better technology assessment and technology utilization can be served best by involving the decision-makers throughout the entire process of technology development and transfer. This is so because it is the users who have the final word in evaluating a new technology.

Most potential users of remote sensing technology are simply unmoved by paper-and-pencil evaluation games. They recognize that externally-prepared benefit-cost ratios exclude many of the considerations most important to them. They see impacts on their own decision processes, job security, and organizational behavior being overlooked and obscured behind voluminous but vacuous evaluative reports. The result for the technology developers is often an evaluative "boomerang effect" in which users perform their own subjective assessments and conclude, for various reasons, that fruits from the technology are not worth their price.

Making Assessments Worthwhile

In contrast to empty evaluations, our notion of a worthwile exercise in technology assessment is pragmatic: we prefer to learn from the users themselves as they grapple with genuine resource management problems. With this perspective, we can observe the *how* and *why* of their decision processes and see *where* technically-derived information can be of use.

It is clear to us that state and local resource managers require more than a few years to adapt a technology as complex as remote sensing to their needs. Adoption of the technology will be an evolutionary process, requiring a multitude of piecemeal adjustments along the way. Contrived calculations and premature evaluations can only serve to divert attention from the more fundamental issues in this process: i.e., how to enable resource managers to make better decisions.

We thus feel it is appropriate that those in the business of developing and applying remote sensing techniques concern themselves less with quantifying the value of new information and more with the means for making better use of the technology. They should be asking not what the technology is worth, but rather how remote sensing applications can be made more worthwhile. Only in this way can we begin to see the technology for what it is really worth.

CHAPTER 7

SPECIAL STUDIES

Chapter 7

PREFACE

As in our previous progress reports we include in this chapter certain highly relevant topics which, although contributed by our various participants under the NASA grant, do not clearly fall within any one of the previous chapters.

Special Study No. 1 of the present progress report, entitled "Social Aspects of Remote Sensing in Perspective" is a highly appropriate and concluding contribution by Dr. Ida Hoos, leader for the past several years of our project's Social Sciences Group. In that brief study she provides a penetrating look at the role of her group, first in such activities of our university's Space Sciences Laboratory as took place in the 1960's and which therefore pre-dated the establishing of our Integrated Study, itself, since its inception in the early 1970's; and finally in activities of the NASA - USDI remote sensing project as conducted during the past 2 to 3 years in Washington,Oregon, and Idaho, and which has commonly become known as the "Pacific Northwest Project."

Special Study No. 2, entitled "The Role of Remote Sensing in Coordinated Resource Planning" is a summary of certain relevant findings and observations of Dr. Robert N. Colwell, Principal Investigator for the Integrated Study, in connection with a separate multi-campus study that is being conducted under his leadership by remote sensing scientists of the University of California with funding provided by NASA's Office of University Affairs.

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BY

DR. IDA HOOS

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SPECIAL STUDY NO. 1

SOCIAL ASPECTS OF REMOTE SENSING APPLICATIONS IN PERSPECTIVE

Janus was accorded first place in the Roman pontifical college because his two faces, one looking forward and the other backward, gave him the advantage of viewing both past and future simultaneously. This privilege is rarely accorded mere mortals, except during those moments in commencement exercises when time is spanned for oratorical and probably inspirational or exhortational purposes. Nonetheless, this special report affords a unique opportunity to review the past and to glimpse the future -- in the activities of the Social Sciences Group.

The history of the Group is intimately associated with the history of NASA itself, for it was established in those halcyon days when NASA could provide generous support to universities for space-related research conceived in the broadest terms. Mr. James E. Webb, Administrator of NASA, was committed to the idea that space-derived and -related knowledge had relevance for mankind and that imaginative research and innovative thinking would translate that knowledge into socially meaningful channels. Dedicated to the proposition that the universities of the land should play a responsible role in the transfer process, Mr. Webb felt that through university effort, the fruits of the national space effort could be more fully realized by the American public. Professor Samuel Silver, then Director of the Space Sciences Laboratory at the University of California, shared this commitment and transmuted it organizationally into the Social Sciences Group, which was founded and, for many years headed, by Professor C. West Churchman, sometime Associate Director of the Space Sciences Laboratory. The roster of participants from this and other American and foreign universities included management scientists, operations researchers, political scientists, lawyers, philosophers, economists, psychologists, and sociologists. The weekly seminars, in the vanguard of the now jejune interdisciplinary orientation, attracted a wide campus and community audience. The list of publications produced in the working paper series, with their scholarly aftermath in the form of journal articles and books, attests to the high level of productivity generated by this intellectually stimulating collegium. Many distinguished careers had their start through the impetus of the NASA-University program. The range of subjects was as diverse as the disciplines; their only common theme, sometimes tenuous at that, was space-relatedness.

Changing philosophies and funding practices at NASA headquarters affected the University program and shifted emphasis somewhat. At the headquarters level, emphasis was identifiable in the passing sequence of buzz words. "Space spinoff" ultimately became so attenuated as to be comparable to hitching a little red wagon to a powerful Percheron. "Technology utilization" made a small subject out of a large predicate by defining its mission narrowly as a very specific, not altogether effective technical information system. Despite superficial oscillations, NASA's concern for exploration and exploitation of its advanced technology remained unchanged and, consistent with this interest, the Social Sciences Group concentrated on the decision-making processes associated with public resource management and with the conditions influencing acceptance of new technical means for data-gathering. Early on, we observed the factors bearing on utilization of remote sensing.

After its early "think tank" years, the Social Sciences Group was "adopted" by Professor Robert N. Colwell, who, as director of the newly developing Remote Sensing Project, had the vision to recognize that emphasis on only the technical aspects of remote sensing was necessary but not adequate in advancing the state-of-the-art. Recognizing that technology does not develop in a vacuum nor does it gain automatic acceptance, Professor Colwell had the courage to support an investment of some of the U.C. grant money in a study of the *social* conditions for the application and adoption of remote sensing technology, of the *process* of the transfer of the technology, and of the down-to-earth dimensions of resource management, where Landsat seemed to have the greatest potential for applicability. Indeed, with California's water resources the focus of the Remote Sensing Laboratory's technical research, the Social Sciences Group had a living laboratory in which to work.

If at this moment of retrospective analysis, one were to admit a bias in the research orientation, one would have to say that it resided in the assumption that space technology has usefulness probably not always immediately evident and certainly not amenable to the type of myopic "evaluation" mandated by current cost/benefit calculation. As to the first point, society is just beginning to become aware of the global proportions of many of its basic problems. This awareness was probably inspired by the view from space; by the same token, space-derived technology will provide the systematic, repetitive information that will help mankind manage its finite resources. One of the lessons learned in the California experience was that advanced technology is not necessarily esoteric; it can be applied globally *or* locally. Its "relevance" depends as much on the state of the user as on the state-of-the-art. In fact, where it is not the actual technology but the fruits of the technology, i.e., the information it can gather, the conventional methodology of assessment is grossly inappropriate. The point to be emphasized is that the *potential usefulness of remote sensing technology does* *not reside in its present uses*, which are limited and hobbled by a number of social, economic, psychological, and political factors.

What is of paramount importance is not *technology transfer*, narrowly conceived, but the *process*, with *scaling up* a vital step. Potential users may not even recognize the potentialities; many of them will no doubt require help in the rudimentary steps of defining their needs. It is likely that models will have to be redesigned to accomodate data in new forms, perhaps to address new categories of questions. Many of the present and future generation of questions transcend old boundaries not only of jurisdiction but of conceptualization. The view from outer space, therefore, may be the one most consistent with Space Age problems.

If there were lessons distilled from research on research in remote sensing in California, they were confirmed by research on applications in the Pacific Northwest. As a direct follow-on to its research in the University's Integrated Remote Sensing Study, the Social Sciences Group was asked by NASA-Ames to conduct a comprehensive case study of the technology transfer occurring in Washington, Oregon, and Idaho. This unique social experiment turned out to be a proving ground for everything that had been learned as well as a challenge to ingenuity in coping with the unfamiliar. Creative management and technical support on the part of NASA-Ames, top level interest from the state governors and their alternates through the Pacific Northwest Regional Commission, sophisticated orchestration by that indefatigable flying squadron -- the Task Force, dedicated participation by USGS -- these were among the elements working together. This being a user-oriented effort, some forty resource and land use planning agencies in the three states could look upon the Project as their own.

With focus on the process of technology transfer rather than on the product, the Social Sciences Group studied the history, the evolution, the organizational structure, and the dynamics of the Pacific Northwest Project. In order to identify key implementing and impeding factors, we studied every facet and tried to understand their interrelationships. Ours was not intended to be a conventional evaluation with results calculated in the customary cost/effective mode. Rather, our emphasis was on the *how*; the insights, garnered from our field research, are the direct results of the social web, so much appreciated by Mr. Ben Padrick of NASA-Ames, and so skillfully tended by his colleague, Dr. Dale Lumb, and by the Task Force. Thanks to the candid and hospitable environment provided, we were exposed to lessons that have relevance not alone to the PNW Project but wherever "advanced" technology is being translated into "relevant" technology, that is, wherever there is an effort to link the state-of-the-art in space concepts to the state of man's earthbound concerns.

Since there is much in the technical transfer process that bears on technology assessment as it is currently practiced, it might be useful to underscore a finding of fundamental importance to both. This has to do with the methodology and models in vogue. In keeping with the canons of ubiquitously applied management science that make quantitative analysis mandatory, cost/effective measures and a favorable ratio are the generally accepted conditions for the successful enterprise. A basic lesson to be derived from the Project was the inadvisability if not the downright undesirability of applying these strictures prematurely. Not only were there the usual problems of assigning numbers where no hard data exist but also the pitfalls associated with quantifying pie-in-the-sky. Moreover, there was considerable evidence of the more subtle perils of forcing the hand of users ready to try but unready to endorse a system whose threat or promise was still to be explored against the background of a social landscape still in the process of being mapped.

A fundamental lesson derived from the earlier and the ongoing research underscores the importance of the social environment in the advancement of remote sensing technology and in the expansion of its sphere of utilization. Contrary to the notion that once the technology has been developed, acceptance and application follow automatically, observation of the social process reveals that this is an example of fallacious "technological optimism". While technical aspects are basic, it is the broad spectrum of human, social, political, economic, institutional, and organizational factors that ultimately determine viability. The study of California water resources and of the Pacific Northwest showed that there is a complex array of social forces that both implement and impede technology transfer. While the findings are pertinent to remote sensing as such, they raise questions and sometimes suggest answers to NASA's longer-range and broader-scale goals in making the view from space a valuable asset to mankind.

SPECIAL STUDY NO. 2

REMOTE SENSING AS AN AID TO COORDINATED RESOURCE PLANNING

BY

ROBERT N. COLWELL

Space Sciences Laboratory

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INTRODUCTION

As stated earlier in this report, the remote sensing of natural resources should not be considered as an end in itself, but as an aid to better resource management, area-by-area. This fact becomes strikingly clear when, as in this Special Study, we consider ways in which remote sensing can facilitate an activity known as "Coordinated Resource Planning."

Coordinated Resource Planning is the term applied to action that involves the cooperative efforts of the various landowners and public agencies that are concerned with the land and resources in a given area, with the objective of bringing about improved management within that area. As stated in a recently published federal document entitled "Coordinated Resource Planning in California" . . . "Coordinated resource planning is a new approach to decision making, that is, how to use the land and resources available to best meet the needs and the responsibilities of the landowners of public agencies involved".

The approach that is employed seeks to use the best efforts and knowledge of everyone involved, -- private landowners, interested Federal or State Agencies and other specialists. As a group they inventory the planning area, analyze the information available, identify and define the objectives, evaluate the various management alternatives that are available, and arrive at management decisions which are acceptable and suitable. The program thus seeks to place total land use planning and resource management in a position of importance for the landowner or operator who must make a living from the land. Simultaneously, it seeks to provide for the maximum multiple use benefits of national interest. Hence any effective demonstration, of the type that we envisage, would need to be conducted within an area that has a desirable mixture of private and public ownership. Furthermore, the demonstration most likely would be all the more meaningful if a rather wide variety of private and public ownerships (and associated resource management interests) were represented within the demonstration area. The entire "resource complex" of the area would need to be inventoried and monitored by means of remote sensing. Hence, procedural manuals such as appear elsewhere in this report should prove to be very useful.

SOME BASIC PREMISES INVOLVED IN COORDINATED RESOURCE PLANNING

Premise No. 1. You can't develop a realistic resource and land management plan until you know existing conditions, limitations and potentials of the area. Much of the required information may already be available, but it needs to be assembled, consolidated, and (in most instances) updated and augmented with the aid of information that is best derived through the use of modern remote sensing techniques, augmented with only limited amounts of direct on-site inspection.

Premise No. 2. To be useful the available information must be understood by all interested parties. Ordinarily this, in turn, requires that the present situation, limitations, potentials and problems are discussed freely so that all participants have a clear picture of opportunities and constraints within which the coordinated resource plan is to be developed.

Premise No. 3. The objectives must be clearly defined. Considerable skill usually must be exercised in accomodating the primary objectives of all of the concerned parties, and in synthesizing these into a clear statement of overall objectives, while at the same time allowing the necessary flexibility for attainment of individual or agency goals. The accomplishment of this difficult task can be facilitated if use is made of remote sensing derived products, such as aerial photographic enlargements, or mosaics made from high-flight photography, or (for very large areas) from space-acquired imagery. Such materials permit all parties to comprehend more clearly both the present situation and the various alternatives that are being proposed.

Premise No. 4. There must be an objective evaluation of alternatives. It is to be expected that with diverse interests there will be different opinions. Only by means of an honest expression of these opinions, followed by an honest appraisal of alternatives, is a compromise likely to be arrived at that will be acceptable to all parties involved.

Premise No. 5. Clear-cut decisions should be arrived at. No Coordinated Resource Plan should be considered complete until the decisions have been reached and expressed in terms that cannot be misunderstood. If there is to be a division of responsibilities, there is all the greater need for clarity of expression in describing the nature of the duties and responsibilities of each participant. Without cooperation there is no coordination and consequently the objectives of the Coordinated Resource Planning efforts will not be achieved.

Premise No. 6. Opportunity must be provided for a subsequent revision of the Coordinated Resource Plan. Re-evaluation of the plan from time to time is necessary in order to keep the plan viable. Conditions change, needs change and objectives therefore may need to be revised. Consequently provision should be made for local planning groups to get together periodically to review accomplishments, acknowledge shortfalls, and develop future plans.

SOME SPECIFIC OBJECTIVIES OF COORDINATED RESOURCE PLANNING

Within California's wildland areas there quite commonly are 5 specific objectives of a Coordinated Resource Plan. It is doubly meaningful to quote these 5 objectives, verbatim, from the previously mentioned document, because it so accurately states what the objectives might well be in developing a Coordinated Resource Plan for any given wildland area in California. These are:

1. Improve the quality and quantity of forage and habitat for domestic animals and wildlife.

2. Maintain and improve the harvest of forest products, compatible with other resource values.

3. Manage the watershed to prevent or reduce pollution, siltation and erosion.

4. Provide for maximum public benefit from the land and its resources, including recreation where practicable, and

5. Improve the economic status of the ranch unit involved.

SOME SPECIFIC STEPS INVOLVFD IN COORDINATED RESOURCE PLANNING

The specific steps that are involved in coordinated resource planning may vary from one locality to another. It is considered relevant, however, to list here the steps that most commonly should be followed. In so doing we will be able to see more clearly that there are many points within this sequence of events, at which remote sensing is likely to be very useful. More importantly, perhaps, this listing will serve to emphasize that remote sensing of natural resource should rarely if ever be considered as an end in itself. Instead it should be considered as a tool which, if properly used, can facilitate wise resource management. Here, then, is a listing of such steps:

Step 1. Define the geographic area within which the coordinated resource plan is to be developed.

Step 2. For this area, identify the owners, agencies and other interested parties.

Step 3. At a meeting where all of these interested parties are adequately represented, obtain a list of the resource-related concerns and goals of each. Then, through group discussion arrive at an agreement as to which "overall objectives" are most important in light of these individual objectives. The resulting product is commonly known as the "Coordinated Resource Plan Objectives".

Step 4. In light of these objectives, define the necessary resource data base, i.e. the basic information that must be available so that specific plans can be developed.

Step 5. Determine how the required information is to be obtained. This, in turn entails a determination of (a) the amount and suitability of existing information; (b) the specific nature of the additional information that is required; and (c) the group or agency that will be responsible for acquiring the additional information.

Step 6. In conformity with the plan developed in Step 5, above, collect the additional information.

Step 7. Display all of the pertinent information on a common base, or otherwise in a readily comprehensible form. Quite commonly the use of a map or a photo-masaic in conjunction with multiple information overlays constitutes the best means of satisfying this requirement.

Step 8. In view of the information that has now been acquired, consider the various resource management alternatives, including the cost effectiveness of each. Analyse these alternatives, comparatively, and select the ones that will be implemented.

Step 9. Based on the individual resource management measures that have been selected in step 8, develop in final form the overall coordinated resource management plan.

Step 10. In light of the capabilities and responsibilities of each participating landowner and agency, decide who will perform each phase of the overall plan and on what time schedule. In addition, if appropriate, arrive at cost-sharing agreements.

Step 11. Implement the plan in conformity with the previously agreed upon time schedule. Remote sensing frequently is useful throughout this implementation phase in directing work crews to the exact spots and via the most suitable routes, and also in monitoring and documenting the rate of progress.

Step 12. At suitable intervals after the implementation of any given aspect of the plan, monitor the results (e.g. the acceleration of tree growth following a thinning operation in a timber stand, designed to release the dominant and co-dominant trees; the increase in wildlife numbers following brushfield manipulation). As appropriate, and based on this monitoring process, revise or update the overall management plan and conduct Coordinated Resource Planning on a continuing basis.

SOME POTENTIAL BENEFITS OF COORDINATED RESOURCE PLANNING

1. One coordinated plan is likely to be more efficient and benefical than several uncoordinated plans.

2. It reduces the chance of overlooking multiple use values of the overall area.

3. It provides an opportunity for all parties to present ideas and discuss the pros and cons of various management alternatives, before a final binding decision is reached. Axiomatically it provides all parties with an opportunity to see where and why adjustments and compromise are needed and why some seemingly worthy ideas cannot be implemented.

4. It increases the participants' knowledge of various government agencies, their policies, their programs, and the reasons for each. As a result it is likely to result in increased public support of such agencies, policies and programs, and also improve working relationships among the agencies, themselves.

5. It is likely to provide more flexibility to ranch operators and more alternatives to problem solving than would be possible without the Coordinated Resource Plan.

SOME POTENTIAL COOPERATING AGENCIES WITHIN CALIFORNIA

There are at least 9 federal and state cooperating agencies within the state of California that are official participants in this program of Coordinating Resource Planning. They are worth listing, since every one of them is a potential participant in the event that we are successful in developing a Coordinate Resource Plan for a wildland test site. They are: Bureau of Land Management (USDI); Forest Service (USDA); Soil Conservation Service (USDA); California Resource Conservation Commission; Cooperative Extension, University of California; California Associations of Resource Conservation Districts; California Department of Fish and Game; California Department of Conservation; and California State Land Division. It is probable that involvement of personnel of our Remote Sensing Research Program of the University of California could be accomplished without adding to this list merely by having them participate through the University's above-listed Cooperative Extension program.

Chapter 8

SUMMARY

Robert N. Colwell

Chapter 8

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In Chapter 1 of this progress report, the question is raised relative to the extent that the potential users in California of modern remote sensing technology are actually accepting and using it. There follows a rigorous definition asserting that the transfer of a technology such as remote sensing can be considered as complete only when that technology, having become readily available in the marketplace, becomes generally accepted practice by the user agency; and the chief officer of that agency, upon routinely assessing all available technology that might be brought to bear on a specific problem, decrees that the technology in question is the one that shall be used. It is concluded that in virtually no instance to date has truly modern remote sensing technology been fully transferred to the managers of California's natural resources, notwithstanding our having compiled an impressive array of letters of praise, written and signed by high officials in the very agencies that we seek most to serve.

Despite this somewhat discouraging observation, our examination of the time-consuming process that leads to the complete transfer of remote sensing technology, leads us to the following more optimistic conclusion: Here in California not only is solid progress being made toward the acceptance of remote sensing technology, but at a rate that is fully as rapid as might have been anticipated or rightfully expected. Two factors that we consider key to this progress are: 1) the very substantial effort that we have made, even from the inception of this Integrated Study, nearly nine years ago, to involve potential users (i.e. the resource managers themselves) thereby ensuring that our efforts were responsive to their needs; and 2) the heavy concentration of our present efforts on the preparation of "Procedural Manuals," each of which describes the step-by-step procedure that our research indicates should be employed in some specific application of remote sensing to the inventory and management of California's natural resources. Both of these items are dealt with in detail elsewhere in this progress report, especially in Chapters 3 through 6.

In Chapter 2, a report is given of water supply studies that are being performed by the Davis campus group. The contents of that brief chapter reflect the orderly transition that has been occurring during the past year (with NASA approval) as the Davis campus team has been bringing to a close its studies as funded under this NASA grant, and transferring its remote sensing-related activities to follow-on programs of the "ASVT" type under separate funding. Thus, their redirected efforts represent a logical step toward bringing about the acceptance of modern remote sensing techniques by various user agencies, especially those techniques dealing with the estimating of water supply.

Chapter 3 describes work that has been performed during the present reporting period by personnel of the Remote Sensing Research Program on the Berkeley campus. As previously mentioned, the emphasis is very largely on the preparation of procedural manuals. Hence, Chapter 3 includes the following items:

In Chapter 3, personnel of our Remote Sensing Research Prgrom (RSRP) on the Berkeley campus report some highly significant progress made during the present reporting period relative to the making of remote sensing-aided water supply forecasts. Emphasis continues to be on the completing of a series of procedural manuals, each of which deals with some specific parameter that needs to be measured with the aid of remote sensing, in making such forecasts.

The first of thse manuals deals with remote sensing as an aid in watershed wide estimation of solar and net radiation. While the procedure described there is self-sufficient for those who are well versed in remote sensing technology, it entails taking certain steps that other users of the manual will find difficult and will require further description. Therefore, cross-referencing to additional procedural manuals, all of which appear as appendices to Chapter 3, is employed. These additional remote sensing based procedural manuals bear the following titles: (1) Geometric correction and watershed boundary determination; (2) Vegetation/Terrain analysis; (3) Topographic analysis; (4) Preparation of climatic data maps for use in radiation and evapotranspiration models; (5) Estimating solar and net radiation in a case study area; (6) Watershed-wide estimation of water loss to the atmosphere; (7) The design and use of 3-level models for estimating evapotranspiration; (8) Determining the areal extent of snow; (9) Determining the water content of snow; and (10) Differentiation of land surfaces.

Consistent with the NASA-approved plan of two years ago, RSRP personnel will concentrate their efforts during the forthcoming year on continued working with personnel of the U.S. Forest Service, the Plumas County Planning Department, and the California Department of Water Resources for two purposes: (1) to obtain an evaluation, from these representative "user agencies" as to the comprehensibility and usability of the above-listed procedural manuals, and (2) to complete a procedural manual desling with remote sensing for the inventory and management of a given area's entire "complex" of natural resources.

Chapter 4 consists of an account of work done during the present reporting period by personnel of the Geography Remote Sensing Unit (GRSU) on the Santa Barbara Campus of the University of California. Most of that work is an outgrowth of the remote sensing-related water demand studies which that group has been performing in the San Joaquin Valley and other parts of central California during the past several years. Their efforts are now being concentrated on the preparation of a Procedural Manual for use in developing a Geo-base Information System. To ensure that this work would be of practical value, personnel of the GRSU have worked closely with resource-related agencies and officials in Ventura County, California.

In developing this Procedural Manual, GRSU personnel have placed major emphasis on learning about the resource information needs at county level. Then, building on their previous work, they have sought to determine the extent to which a meaningful Land Cover Classification for use in Ventura County could be made from an analysis of remote sensing data as acquired by the Land Multispectral scanner. Recognizing the ready availability of information about topography and other terrain characteristics (e.g. through the use of DMATC Digital Terrain Tapes), they have then demonstrated how that information could be merged with the Landsat-derived land cover information.

In Chapter 5 of this Progress Report, two major topics are dealt with by the Remote Sensing Group on the Riverside campus. Both of these topics are outgrowths of studies which that group has made during the past several years on uses that can be made of remote sensing in estimating water demand.

The first of these topics deals with techniques for mapping land use from remotely sensed imagery. Several months ago, these techniques served as the basis for a Procedural Manual which was prepared in preliminary draft form and which has since been submitted to a potential user agency, viz. the Los Angeles Division of the California Department of Water Resources. While general reaction to the Procedural Manual was quite favorable, there was a concensus that:

(1) it is not sufficiently detailed;

(2) in some portions of it, the procedures to be followed need to be expressed more clearly, and

(3) the time required and associate costs incurred for each of the various procedural steps should be documented.

Each of these suggestions is eliciting a positive response by the Riverside group. For example, in the present Progress Report, the time requirements and production costs are reported, in one representative instance, for each of the seven steps entailed in producing a land use map by means of computer techniques.

The second major topic dealt with by the Riverside group in this Progress Report is a Spatial Information Processing System. As part of the Riverside group's efforts under this NASA grant during the past several months, that system has been steadily evolving and is now almost fully developed. The system consists of a suite of related computer programs which can be used to perform selected tasks with respect to processing information about the natural resources of an area. Since much of that information is derived through remote sensing, the development of this Spatial Information Processing System (SIPS) has become a vital part of this "integrated study." As specific evidence of this fact, the present Progress Report describes in considerable detail how SIPS can be advantageously used in relation to four major tasks of concern to the resource manager; (1) Map Data Encoding; (2) Geographic Data Base Creation; (3) The Production of Graphic Output in the Form of Computer-Generated Maps; and (4) Data Structure Conversion.

Based on this work, the Riverside group is in the process of preparing a Procedural Manual dealing with the computerization of remote sensing-derived information and related data on land use.

Chapter 6 contains the final report of the Social Sciences Group that has been involved with this Integrated Study for the past several years. Quite appropriately that chapter (for which Dr. Ida Hoos is the co-investigator) deals with remote sensing in California in terms of the social aspects of technology transfer and assessment. At the outset, Chapter 6 acknowledges two important contributions that have resulted from work done during the past several years under various phases of this grant: (1) the impetus that has been given to the transfer and continued evolution of remote sensing technology by individuals who, in times past, received their training in remote sensing primarily through their own employment on this NASA-funded remote sensing project; and (2) the similar impetus that has been given because of the strong user orientation that has characterized this study since its inception.

Next, it is emphasized that, since the project's inception, our Social Sciences Group has been examining "the institutional dynamics, social environment, political ramifications, and economic consequences surrounding applications of remote sensing technology." Chapter 6 constitutes a summary of that examination and of the role which the Social Sciences Group has played in instituting and reinforcing linkages between two communities: (1) a community of technical specialists (i.e. the remote sensing scientists of the University of California) and (2) a community of resource managers (i.e. the managers of California water resources and its associated vegetation resources, such as timber, forage and agricultural crops). The potential importance of procedural manuals, such as those appearing elsewhere in this report as aids in instituting and reinforcing such linkages, is acknowledged by the Social Sciences Group.

The remainder of Chapter 6 discusses in sequence, the following remote sensing-related aspects: (1) the technology itself; (2) the user community; (3) technology transfer; and (4) technology assessment.

The following aspects are emphasized in connection with the technology itself: (1) earth resource satellites seek to harvest the earth's "information crop;" (2) remote sensing practitioners are heavy borrowers from more established disciplines; and (3) with a history that links modern day remote sensing with both military surveillance and space exploration, remote sensing tends to be tainted with "spy-in-the-sky" labels by some, and with "pie-in-the-sky" labels by others. This section concludes with a discussion of the basic set of elements that are common to most remote sensing activities.

With respect to the user community, Chapter 6 points out the following facts: (1) many organizations that are commonly considered to be part of the user community, commonly might more appropriately be regarded at the present time merely as "potential users;" (2) the progress which any such organization makes toward becoming a true user of modern remote sensing technology, depends on many factors including those which are political, economic and/or behavioral; (3) of the user groups, few can offer a greater variety of resource management functions and approaches than state and local governments; (4) without the support of such governments, federal plans for the management of natural resources can be subject to erosion and emasculation; and (5) for a potential user to accept and adopt remote sensing technology, he must find it sufficiently more economic and efficient to justify using it to replace whatever system presently is being used. Reflecting the emphasis which our Integrated Study has given to water resources, this section of Chapter 6 concludes with an analysis of the informational requirements of water resource managers, the progress that is being made toward satisfying those requirements, and the extent to which the managers of other components of the natural resource complex can apply such water-related experiences in their search for some means of improving their own resource inventory and management efforts.

In beginning their discussion in Chapter 6 of technology transfer, Hoos et al assert that our Integrated Study, viewed in its entirety, can be regarded as "a continuing effort in technology transfer" in that it "comprises parallel threads of research, research assimilation, and application of research to California resource problems." The fact that application of research findings almost never is achieved in a single step, explains why technology transfer is considered a process. That process commonly can be portrayed as involving the following five stages along an S-shaped learning curve: (1) awareness; (2) interest; (3) evaluation; (4) trial; and (5) adoption.

The Social Sciences Group concludes by discussing aspects related to these five stages.

As in our previous progress reports, we include here an additional chapter (Chapter 7) containing certain highly relevant topics which, although contributed by our various participants under the NASA grant, do not clearly fall within any one of the previous chapters.

Special Study No. 1 in Chapter 7, entitled, "Social Aspects of Remote Sensing in Perspective" is a highly appropriate and concluding contribution by Dr. Ida Hoos, leader for the past several years of our project's Social Sciences Group. In that brief study, she provides a penetrating look at the role of her group, first in such activities of our university's Space Sciences Laboratory, as took place in the 1960's and which therefore pre-dated the establishing of our Integrated Study; then in the activities of our Integrated Study itself, since its inception in the early 1970's; and finally, in activities of the NASA-USDI remote sensing project as conducted during the past 2 to 3 years in Washington, Oregon and Idaho, and which has commonly become known as the "Pacific Northwest Project."

Special Study No. 2 of Chapter 7, entitled, "The Role of Remote Sensing in Coordinated Resource Planning" is a summary of certain relevant findings and observations of Dr. Robert N. Colwell, Principal Investigator for the Integrated Study, in connection with a separate multi-campus study that currently is being conducted under his leadership by remote sensing scientists of the University of California, with funding provided by NASA's office of University Affairs.